

The Lift-Fan Aircraft: Lessons Learned

Wallace H. Deckert

Ames Research Center
Moffett Field, CA 94035-1000

Prepared for
Ames Research Center
CONTRACT NAS2-5364D
March 1995 .



National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035-1000

CONTENTS

	Page
Introduction	ix
Summary of the Technical Presentations by	
Wallace H. Deckert, NASA Ames retiree. Missions, lift-fan aircraft design studies, contractual full-scale research, and flight test of the Avrocar	1
David H. Hickey, NASA Ames retiree and Jerry V. Kirk, NASA Ames staff. Lift-fan induced airframe aerodynamics, cross-flows and inlets, large versus small-scale results, thrust vectoring, and acoustics	9
Woodrow L. Cook, NASA Ames retiree. Flight characteristics of designs and real aircraft, related wind tunnel investigations, and recent experience with a lift-fan aircraft development project	23
James A. Franklin, NASA Ames staff. Stability and control, including computer, fixed-based, and moving-base piloted simulations; and lift-fan related results from VSRA aircraft flight investigations	37
Ronald M. Gerdes, NASA Ames retiree. Pilot's perspective. XV-5B and other flight activities, and piloted moving-base simulations at NASA and elsewhere	51
References	58

Acknowledgements

- To Mr. John Burks of NASA Ames for creating this activity as delineated in the section Abstract.
- To Mr. Clark White of NASA Ames, the contracting Officer's Technical Representative, who provided outstanding "real time" leadership.
- To hundreds whose names are not in this report, but if such acknowledgements were possible, should be.

Abstract

This report summarizes the highlights and results of a workshop held at NASA Ames Research Center in October 1992. The objective of the workshop was a thorough review of the lessons learned from past research on lift fans, and lift-fan aircraft, models, designs, and components. The scope included conceptual design studies, wind tunnel investigations, propulsion system components, piloted simulation, flight of aircraft such as the SV-5A and SV-5B and a recent lift-fan aircraft development project. The report includes a brief summary of five technical presentations that addressed the subject The Lift-Fan Aircraft: Lessons Learned.

Introduction

In 1992 Mr. John Burks of the Aircraft Technology Division, NASA Ames Research Center, initiated an activity to review the lessons learned from past lift-fan aircraft research investigations. The time period was 1956 to 1992. The scope of work included NASA retirees and present staff authoring five written technical papers, one oral presentation, and the conduct of a Workshop on October 28 & 29, 1992. The five written papers are summarized in this report. The oral presentation by Laurence Gertsma of NASA Lewis is not included as reference material was not available.

The objective was a thorough review of the lessons learned from past research on lift fans, and lift-fan aircraft, models, designs, and components. Scope included conceptual design studies, wind tunnel investigations, propulsion system components, piloted simulations, flight of aircraft such as the XV-5B, and a recent lift-fan aircraft development project. One hope is that this effort will help foster the continued advancement of light-fan aircraft technology, and do so "without reinventing the wheel".

The first lift-fan aircraft research investigation in the nation featured a "lift fan" in a two-dimensional wing. This research, by Mr. David H. Hickey of NACA Ames, was initiated in 1956. Since then, NACA, NASA, their contractors and others have authored hundreds of publications on lift-fan aircraft technology.

Most of the lift-fan aircraft research was applicable to subsonic aircraft. For supersonic lift-fan aircraft, takeoff, landing, conversion to and from powered-lift flight, and some mission legs are at subsonic speeds. This fact, and because some research was generic, makes some subsonic research applicable to supersonic aircraft. Some research was specific to supersonic aircraft.

Lift-fan aircraft research was applicable to all categories of powered-lift including those known by the acronyms STOL, VTOL, V/STOL, and STOVL. Too many understand these acronyms superficially. See Reference 1, Appendix I for definition and design implications of these acronyms.

Lift-fan aircraft are competitive throughout the powered-lift spectrum; STOL, VTOL, V/STOL, and STOVL. They are applicable to supersonic and subsonic, civil and military, fighter and transport, and personal aircraft.

The applicability of lift-fan aircraft is partly because vertical flight often requires dynamic vertical flight as opposed to sustained steady-state hovering flight while in the vertical flight mode. Design and operational considerations differ for dynamic vertical flight and sustained hovering flight. Differences occur with respect to fuel usage, reingestion, FOD, visibility, noise,

nonproductive time, ground-effect-induced performance changes and attitude upsets, detectability, and site preparation. A lesson learned was that differences favor dynamic vertical flight, often by a wide margin.

Summary of the Technical Paper by Deckert, Reference 1

Mission Applications

Though promising for certain missions that require sustained hovering, lift-fan aircraft are most promising for missions that require dynamic vertical flight. Example missions that require hover are those for which time is of the essence and radius of action is long, such as oceanwide search and rescue. Though lift-fan aircraft could be utilized for today's missions, they are better characterized as yielding new civil opportunities and new military strategies. Many examples of both are presented.

A view that is too limited is that lift-fan aircraft are promising because of their takeoff and landing capability such as STOVL or V/STOL. A lesson learned was lift-fan aircraft are promising for many reasons, such as (1) short or vertical takeoff and landing, (2) near-terminal departure and approach patterns, (3) up-and-away flight performance, (4) maneuverability, (5) design tradeoffs such as wings designed for cruise and not compromised by takeoff and landing, (5) advantages from ground facilities such as ski-jumps, (6) total system savings such as not requiring the aircraft carrier to turn into the wind, and (7) much more.

Lift-Fan Aircraft Design Studies

The section begins with the first NASA lift-fan aircraft design, an in-house effort published in 1964. A lesson learned was the knowledge gained by including reference aircraft on each side of the powered-lift spectrum compared to the aircraft under study. If design is about STOVL, then the scope should include designs to the same mission (as much as possible) of one V/STOL and one STOL.

The second design effort was contractual studies in the mid 1960s, figure 1. Lessons learned included:

- * The importance of preparations. Prior to go-ahead, NASA spent months on design goals and criteria.
- * The weight advantage by using burning reaction control nozzles, and how to select their design point so that only rarely is the burning feature ever initiated.
- * "A red flag of warning" that pure fan-in-wings may not be competitive with other lift-fan configurations.
- * Advantage in gust sensitivity, due to the lift-fan concepts high wing loading and low-aspect ratio and swept wing.
- * Caution required before concluding that lift-fan aircraft are noisier or quieter than other concepts.
- * That lift-fan aircraft have "time on their side", because the impact of advancing technology favors the concept.
- * Sensitivity of short-haul economics to nonproductive

time, and how the lift-fan deceleration capability can be used to minimize nonproductive time.

- * Need to periodically review the "lift-fan family-of-aircraft concept". If a "second best" lift-fan STOL uses much of the same propulsion as its vertical flight counterpart, then the STOL will not be second-best for the total system.

Another study was on V/STOL lift-fan research transports, figure 2. One lesson learned concerned design goals for research aircraft, which are different than those for operational aircraft. Many design goals for research aircraft are less demanding. A lesson learned was to give consideration to the opposite case. That is, to specify which of the design goals for research aircraft should be tougher than for the operational aircraft. Higher control power during low-speed flight and other examples are presented.

A study in the 1970s was on V/STOL short-haul transports, figure 3. Aircraft were designed for either engine or lift-fan failure. Lessons learned included:

- * Not to assume about V/STOL performance. A case is presented in which VTOL had greater range than 1000 ft STOL.

- * That maximum ground roll acceleration does not occur when thrust is pointed straight down the runway.

- * For aircraft with equal number of engines, that V/STOL has higher dispatch reliability than CTOL.

- * Civil and military V/STOLs (unlike VTOLs and STOLs) have much different design points.

- * Unlike for CTOLs, the best V/STOL design is one that is non-optimum for the primary mission.

- * Implications of the above for a STOVL program.

In the 1970s NASA studied military STOVL aircraft for Vertical-Onboard-Delivery, figure 4. Lessons learned:

- * The compatibility between military and civil lift fans.

- * Initial understanding of two-stage lift fans.

- * The quad entry scroll and its possible application to a STOVL supersonic fighter.

Next were studies of Navy multimission STOVL aircraft, figure 5. Lessons learned included:

- * The design flexibility available if lift fans are interconnected by gas duct or mechanically. Flexibility is more important for multimission than for single mission design. The same basic multimission in this study had 2 or 3 gas generators as a function of the specific mission.

- * The importance of gyroscopic coupling. Even after minimizing with opposite rotation of parts, one design was limited by gyroscopics in nacelle incidence rate and aircraft roll rate. Should a STOVL design with one 2-stage fan-in-fuselage have counterrotating stages?

The final design study presented in the paper is on military multimission research and technology aircraft,

figure 6. Lessons learned included:

- * Understanding of the Scroll-in-Scroll concept, and importance of continuing advancement of scroll technology.
- * The inherent safety and other features of a low-speed control system that uses both Energy Transfer Control (ETC) and Thrust Reduction Modulation (TRM).

Design Integration

Presented are full-scale experimental investigations on manifolding of gas generators, interconnect ducting, and the Energy Transfer Control system. Lessons learned included:

- * Manifoldded gas generators, figure 7, are insensitive to transients, even those due to gas generator failure. The time that transient lift loss can be tolerated in flight will dictate design and valve closure rates rather than gas generator or other propulsion component sensitivities.
- * Full-scale metal and composite interconnect duct segments were promising. The semi-flexible composite ducts offered advantages of weight, both by weight per length and by elimination of heavy connecting elements such as bellows.
- * An Energy Transfer Control system, figure 8. The paper lists 10 lift-fan aircraft low-speed control systems and presents the promising results from full-scale experimental investigations of Energy Transfer Control.

The Avrocar Flight Evaluations

The author was the USAF project manager of flight evaluations of the Avrocar, figure 9. Lessons learned were:

- * The Avrocar was flown first; put in NASA's full-scale tunnel second. That sequence of events was backwards.
- * The importance of the performance of gas ducts.
- * The unacceptability of pure thrust spoilage control.
- * Huge changes from small changes of ground height.
- * The asymmetry exhibited by symmetric-looking aircraft. A STOVL fan-on-fuselage-centerline is not symmetrical.
- * Gyroscopics, though typically adverse, can be harnessed and used favorably, as on the Avrocar for stability.
- * The many favorable effects from operationally taking VL to mean almost Vertical, not purely Vertical, Landing.
- * The toughness of lift fans, as exemplified by this very first flightworthy lift fan.
- * Importance of an acceptable cockpit environment.

Concluding Remarks stress need for lift-fan technology aircraft. Such projects exercise the too-inactive contractual design teams; augment R & T base; include fabrication, qualifications, flight technology demonstration, and long-term flight research; and for mature technology like the lift fan, are the mechanism that enables application.

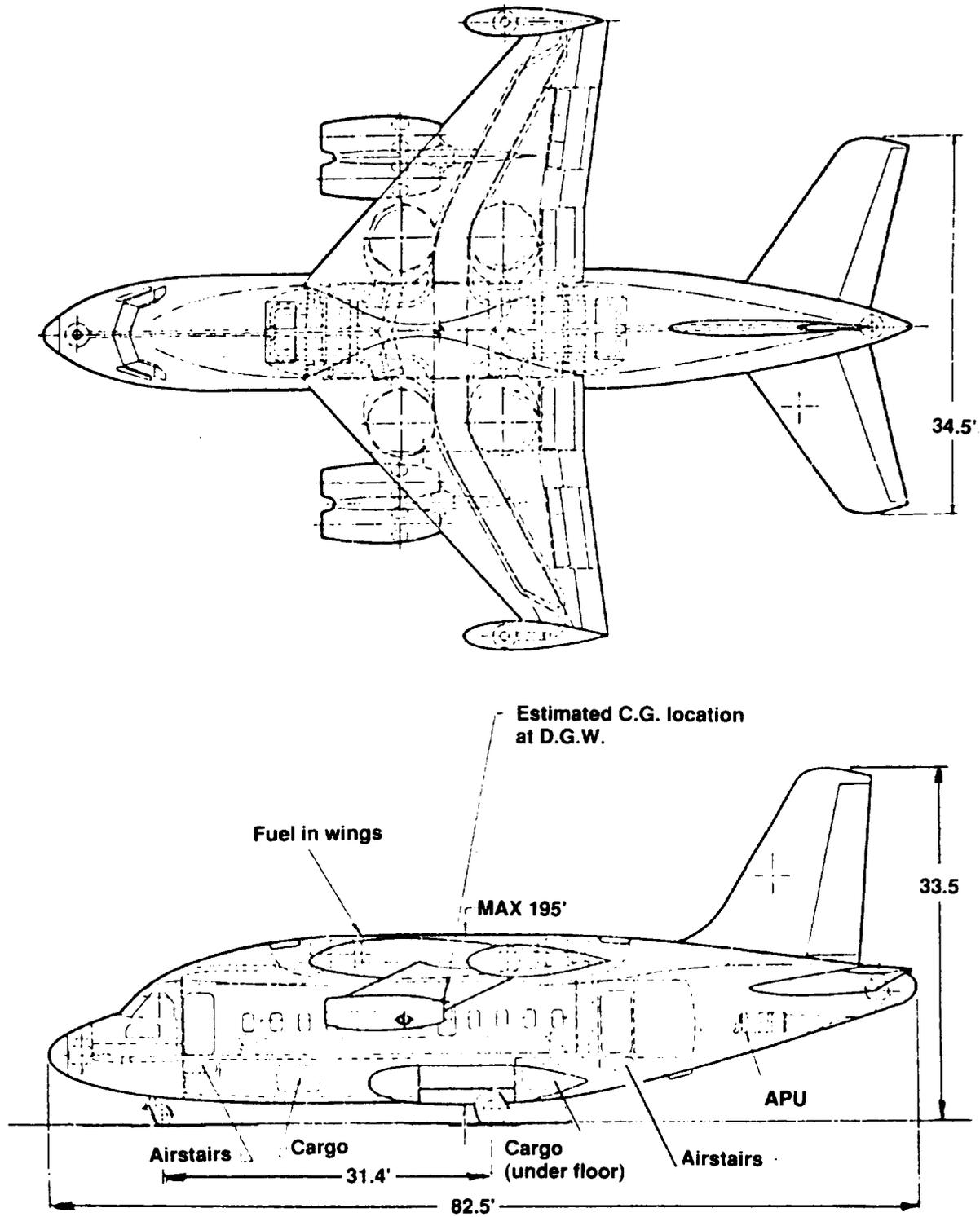


Figure 1. Boeing 60-passenger VTOL lift-fan aircraft design.

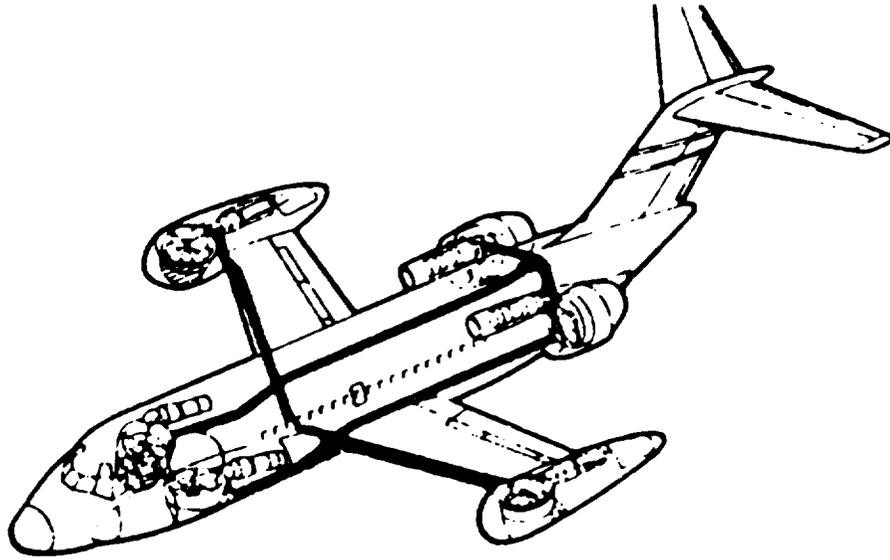


Figure 2. McDonnell modified DC-9/STOL lift fan plus lift/cruise fan research transport design.

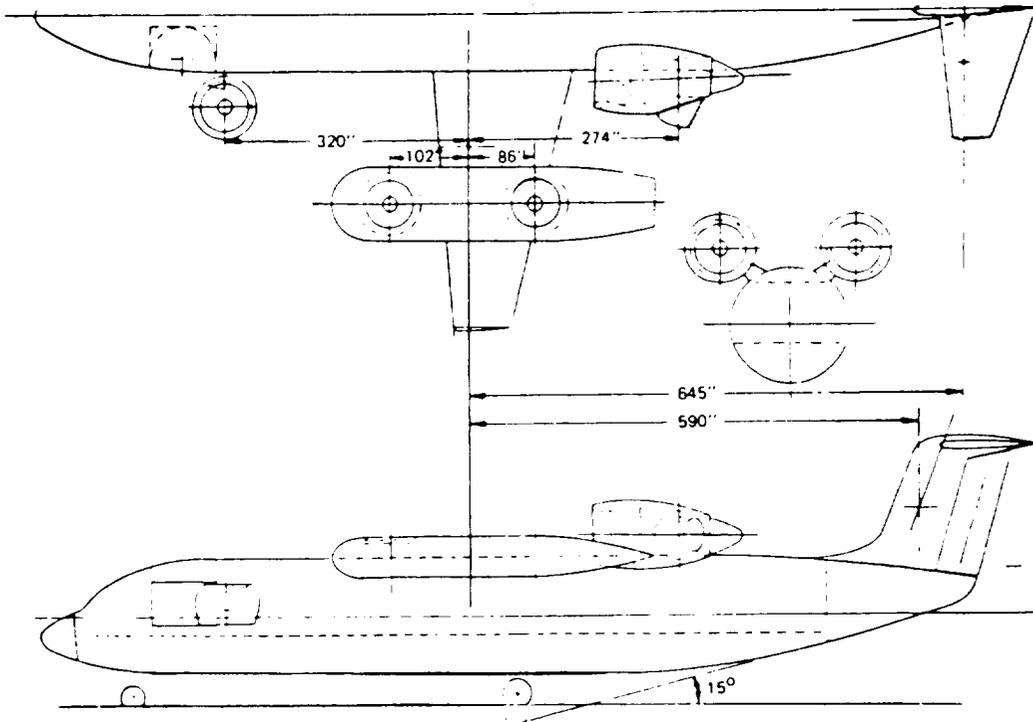


Figure 3. Boeing 100-passenger V/STOL integral lift-fan transport design.

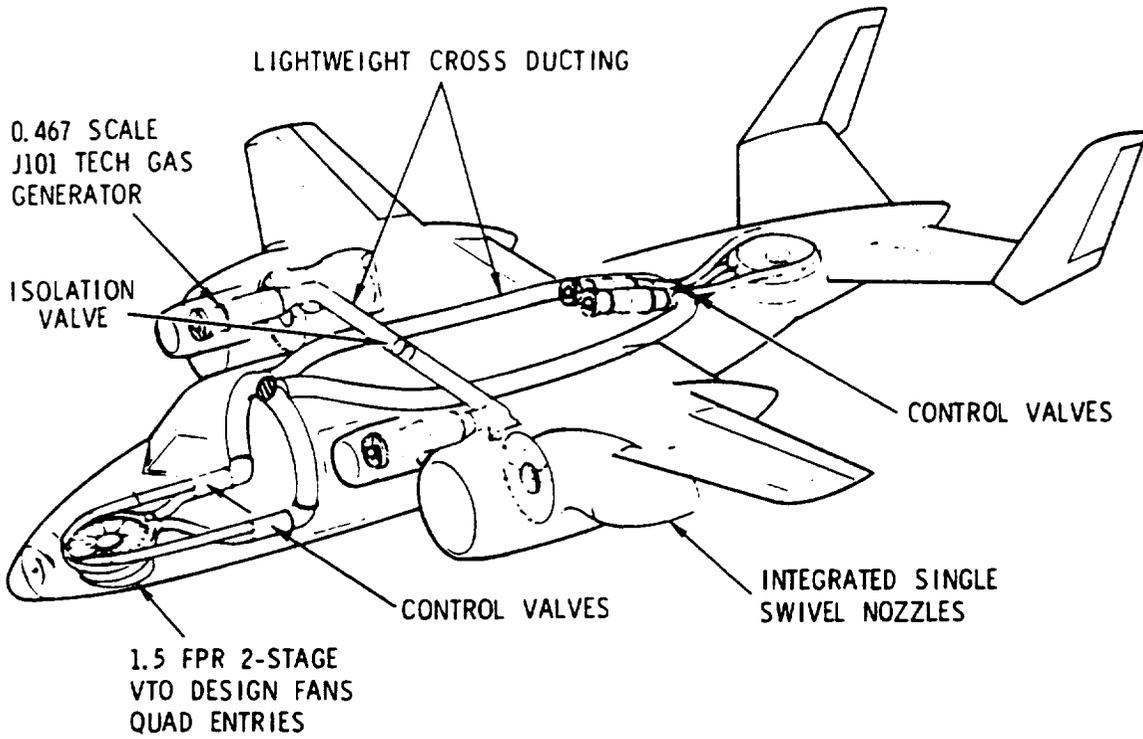


Figure 4. Rockwell STOVL design for Navy Vertical-Onboard-Delivery.

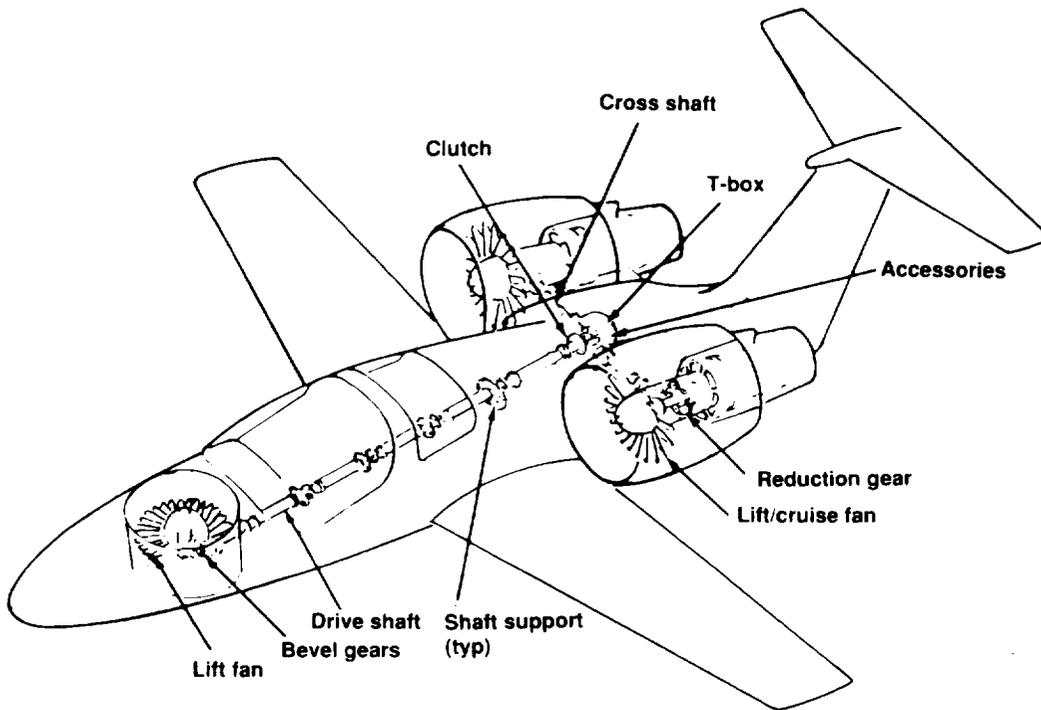


Figure 5. Isometric of Boeing Navy multimission design

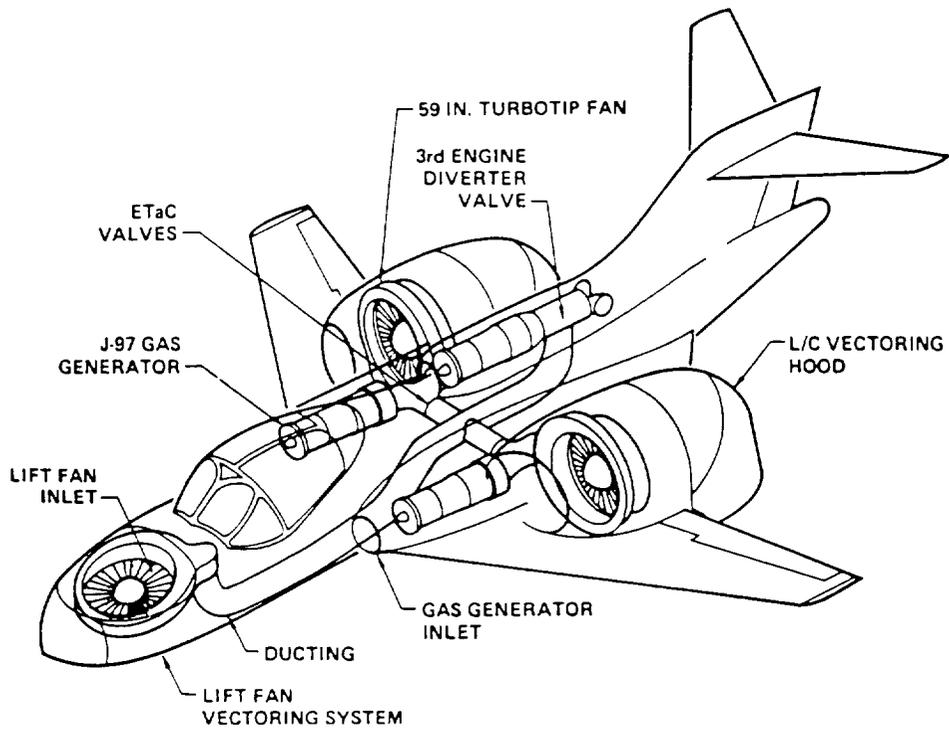


Figure 6. McDonnell modified T-39 RTA V/STOL aircraft design.

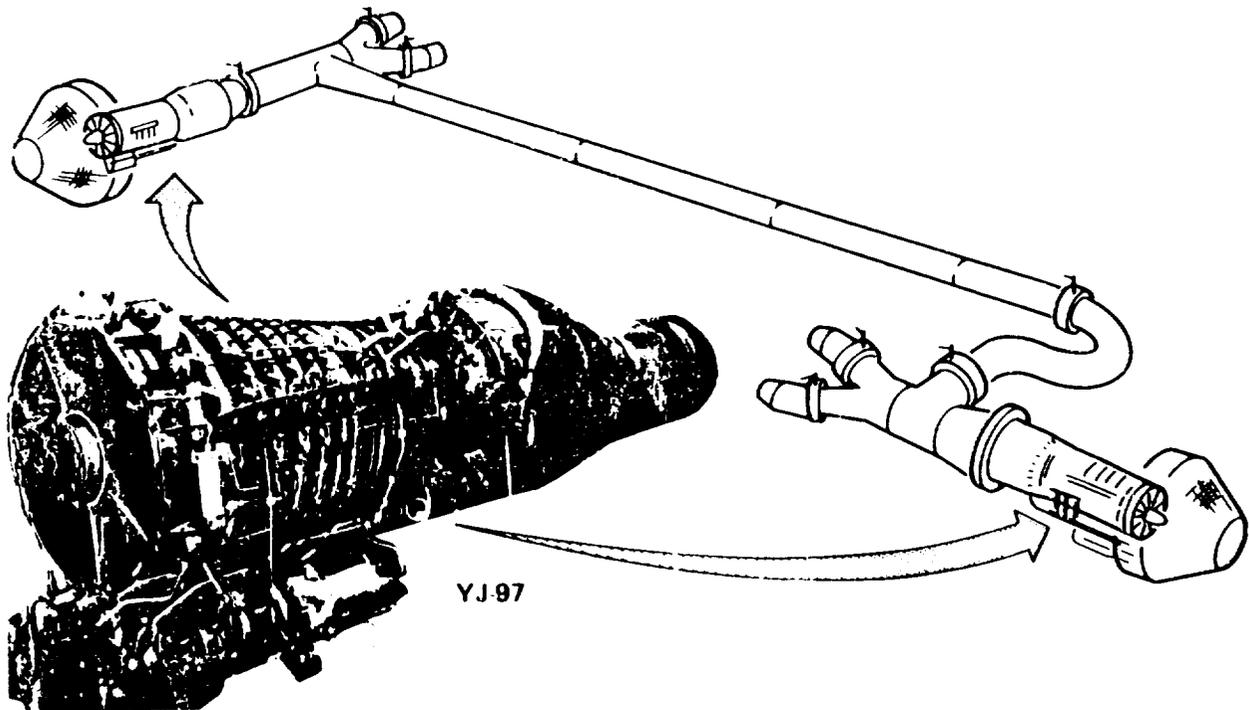


Figure 7. Full-scale investigation of characteristics of manifolded YJ-97 gas generators.

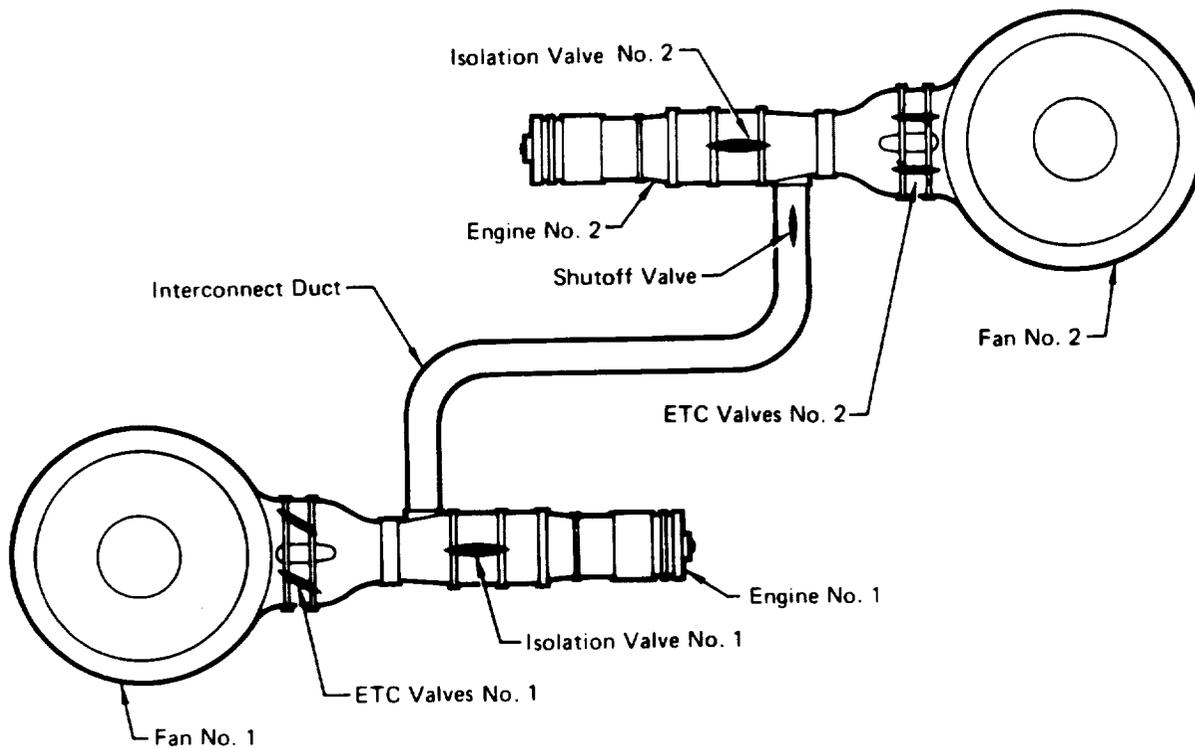


Figure 8. General arrangement of a paired Energy Transfer Control system.

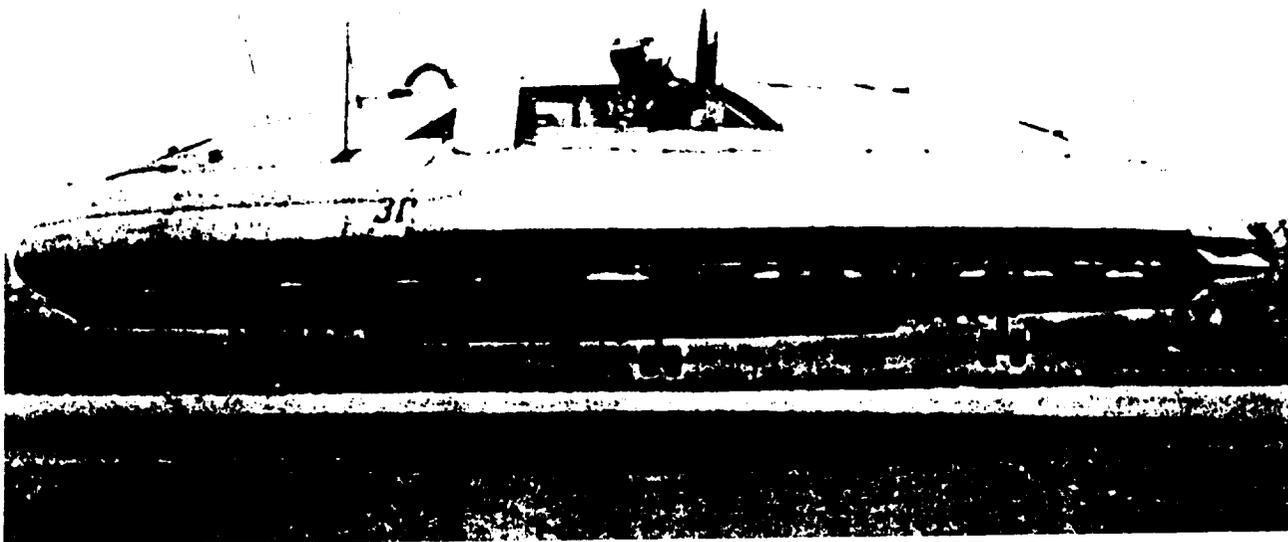


Figure 9. USA VZ-9AV/Avro Aircraft Limited Avrocar hovering 1 foot above concrete.

Experimental Modelling

For CTOLs viscous and scale effects must be considered. For STOVLs it is further complicated by the necessity to model propulsion and free stream mixing and entrainment. This impacts acceptability of powerplant simulation.

Figure 10 shows viscous effects for tilt duct lip flow separation. Though the small-scale duct was of reasonable size (17 in dia), the inner lip stalled 35 deg before the full-scale. Outer lip differences were greater. Another result was that 1/6 scale cascade vanes had a major loss in turning efficiency compared to the full-scale cascade.

In 1960 NASA Ames studied the first large-scale model with a fan (5.2 ft dia) mounted in the fuselage. Primary differences between this model and a 1/9 small-scale model were in the fan blade geometry itself and the stator. Figure 11, lift variation with forward speed, shows there was a problem with the small-scale simulation. The difference is contrary to Reynolds Number effects. The swirl in the small-scale exhaust and different exhaust profiles probably resulted in different mixing and entrainment rates.

Another investigation utilized two large-scale fans but of different pressure ratio. Induced lift and other results differed. This work indicates that it is not enough to model an axial flow fan with another axial flow fan; exhaust characteristics must be modeled as well.

Work at NASA Langley showed importance of exhaust decay on induced hover lift loss. Small-scale results on figure 12 could not be duplicated which led to study of test facilities. Results are affected by test chamber volume, relative size and texture of the ground plane, and model exhaust characteristics. At present level of understanding, accurate ground effect results can only be assured by testing large scale with realistic power plants, outside where test chamber volume is infinite. Figure 12 shows full-scale engines had more suckdown than small-scale results. Figure 13 shows lift increment in ground effect for VAK-191B STOVL and 10 % scale model. VAK suckdown is twice that of the model. The above and more lead to these lessons learned:

- * Study Reynolds number sensitive devices at large scale
- * Propulsion systems must be accurately modeled for transition aerodynamic studies
- * Ground effect studies require (1) well modeled propulsion systems and (2) an open air test site
- * Propulsion modeling must be large scale and the engine similar to that planned

STOVL Components

Emphasis is on inlets and exhaust devices. For STOVL, inlets range from shallow for fan-in-wing to deep for fan-in-fuselage. Thus, work on lifting engine inlets is included.

In 1956 NASA (i.e. Hickey) conducted the first wind tunnel test of a fan-in-wing model. Figure 14 shows the next effort in 1958 using a fan (i.e. a 20 in dia propeller) in a wing semispan. Results were used to design the XV-5. Results show for velocity ratios where fan blades are highly stressed (below $V/V_j=0.3$), streamwise and spanwise flow distortion was small. Thus in 1958 it was already questioned whether lift-fan inlets needed flow turning devices.

From early work on thick wing subsonic designs, attention turned to the thin wing supersonic designs. To provide a thin fan for thin wing models, the stator was removed from the X-353 and BLC was used on the outboard part of the inlet, see figure 15. Except for the unmodified hub, this first thin fan could fit in a 60 deg swept back triangular wing 5 % thick. Large-scale aircraft model results using this thin 5.2 ft dia fan show, compared to the thick fan, (1) about equal static performance, (2) slightly better forward speed performance, and (3) effectiveness of the BLC - a jet of magnitude 3 % fan thrust increased fan thrust 30 %. This and other research lead to questioning whether a thin fan in a supersonic wing could be shaft driven because of depth of right angle gear drives, or if it could have variable pitch because of depth of pitch change mechanisms.

Turning to deep inlets, figure 16 shows lift engines (J-85s) in a large-scale model. Figure 17 is a comparison of the deep inlet of figure 16 and others also discussed. One conclusion is that a small amount of tilt and using the tilt to increase the upstream inlet radius is a powerful tool to improve recovery and minimize distortion.

The paper includes a section on exhaust deflectors that range from cascades of vanes to multi-segmented hoods to rotating tail pipes.

Lessons learned pertaining to this section on STOVL component aerodynamic design include the following.

- * Lift fans
 - * Lift-fan inlets don't need flow turning devices
 - * BLC inlets reduce fan depth and are highly effective
 - * Small tilt of a thick duct improves fan performance
 - * Fan should be near top of duct

- * Exhaust deflectors
 - * Cascades can deflect fan flow 60 degrees
 - * Lift/cruise fan deflectors have a 6 % thrust loss

STOVL Aerodynamics

The section emphasizes ground effects and transition aerodynamics during the powered-lift flight mode. Ground effects during hover, because of referenced coverage by others, is not discussed except for exhaust gas reingestion. Of potential problems, a catastrophic one is engine stall from the ingestion of cells of hot air. Such was recognized early and was the driving reason for the shape and arrangement of the XV-5. The problem could become worse because new designs will probably have higher temperature engines. Considerations for solution include configurational layout, exhaust deflection, and operational procedures.

Ground effects at forward speed can be measured in a wind tunnel, even in those not equipped to eliminate the wind tunnel boundary layer. Sometimes investigators artificially limit testing because of wind tunnel flow breakdown. Tests should continue to that low speed at which exhaust flow reflections impinge on the model.

Operation of lift fans in transition can induce major forces over and above those from direct thrust. A jet-in-crossflow, figure 18, entrains air from the surrounding environment and may induce negative lift on surfaces. Most results and prediction techniques for jet-in-crossflow rely on experiments with wall jets. The wall acts as a plane of symmetry and prevents flow across that plane. Few aircraft are configured in that way so jet trajectories, entrainment, and induced forces could be different. Such a case that involved operation of the XV-5 nosefan is discussed.

Transition aerodynamics must be understood, and it is one of the reasons for wind tunnel investigations of many aircraft geometries. Figure 19 tabulates major parameters of 13 large-scale lift-fan powered models that were tested in the 40-by 80-ft tunnel. Figure 20 shows the variation of induced lift with airspeed for several of the models. A fan mounted near the wing trailing edge produces positive induced lift. Some geometries yield no, or even very negative induced lift. Concern is not just with induced lift itself, but that induced lift also induces pitching moments. Figure 21 shows pitching moment variation for several lift-fan installations. As shown fan-in-wing types can exhibit large positive changes in pitching moment. The moment variation from podded configurations is less, and easier to handle.

Lessons learned for this section include:

- * Turbulent hot gas cells stall engines. The reingestion is controlled by configurational layout, by exhaust deflection, and by operational procedures.
- * Lift-fan operation induces a substantial downwash, provides induced lift, and induces moment.

Prediction Methods

Recognized is the need for sophisticated prediction techniques using paneling and complex models of the jet in crossflow. Stressed is the usefulness of simple semiempirical prediction. The methods presented are compatible with a personal computer. Addressed are Ground Effects, Jet-in-Crossflow, Fan-in-Wing, and Tilting Lift/Cruise Fans. To illustrate this section, the Fan-in-Wing is summarized.

A fan-in-wing can be represented by a mid-chord jet flap, located anywhere spanwise or chordwise as long as it is bounded by the wing. As shown in figure 22, a two-dimensional lift coefficient is developed for the wing section through the fan. Two-dimensional jet flap theory is used for lift on the wing section upstream of the fan. Since the aft section of the fan has separated flow on the under surface, a lift coefficient of $-V/V_j$ to the $3/2$ is assigned. Front and rear lift coefficients are joined to give a complete two-dimensional lift coefficient inside the brackets (see figure 22 equation). The terms outside the brackets convert to three dimensions and from lift coefficient to lift ratio. Predictions are compared to measurements for induced lift, lift ratio, moment variation, ram drag, total horizontal force, and more. Figures 23, 24, and 25 are included herein to illustrate these comparisons. Agreement is sufficient for usefulness of these simple methods.

Lessons learned for Prediction Methods include:

- * Jet flap and 3-D wing flap theory induced lift prediction method
- * Momentum methods for thrust/drag
- * Momentum/jet flap for lift/cruise

Acoustics

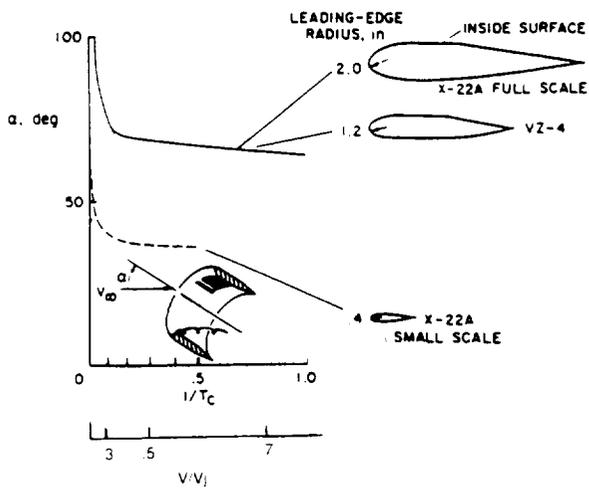
The paper includes a section on acoustics. Lessons learned and/or findings are:

- * A number of ways to minimize lift fan noise will not compromise performance or volume, and therefore should be included in any design.
- * An increase in fan depth and added treatment can further reduce noise, but with penalty.
- * A thin statorless fan can have noise levels comparable to the best conventional fan.
- * Forward speed increases lift fan noise and jet mixing noise.

Concluding Remarks

This is a comprehensive paper with 90 figures, most of which are presentations of technical results.

DUCT ANGLE OF ATTACK AT WHICH INNER LIP STALL OCCURS



DUCT ANGLE OF ATTACK AT WHICH OUTER LIP STALL OCCURS

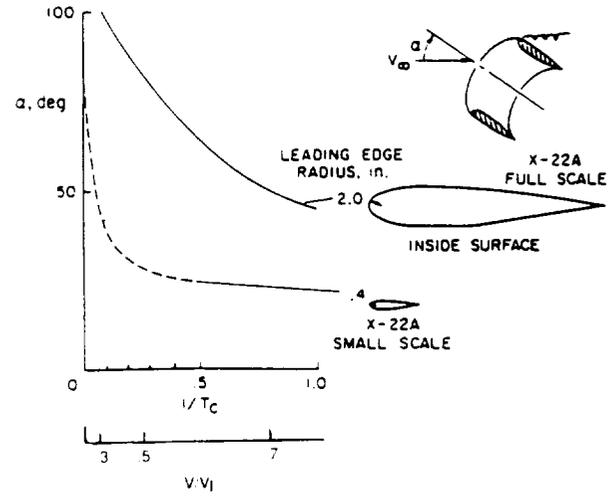


Figure 10. Effect of Reynolds number on duct inlet flow separation.

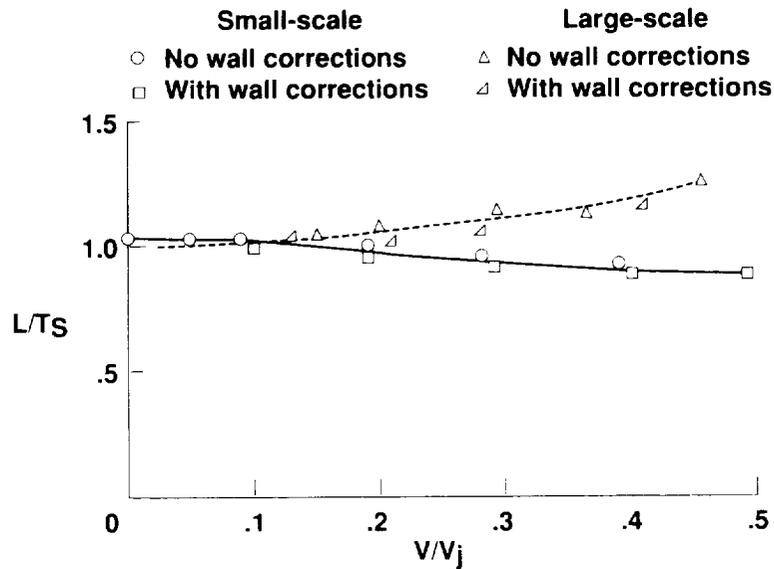


Figure 11. Comparison of small- and large-scale model lift variation with forward speed.

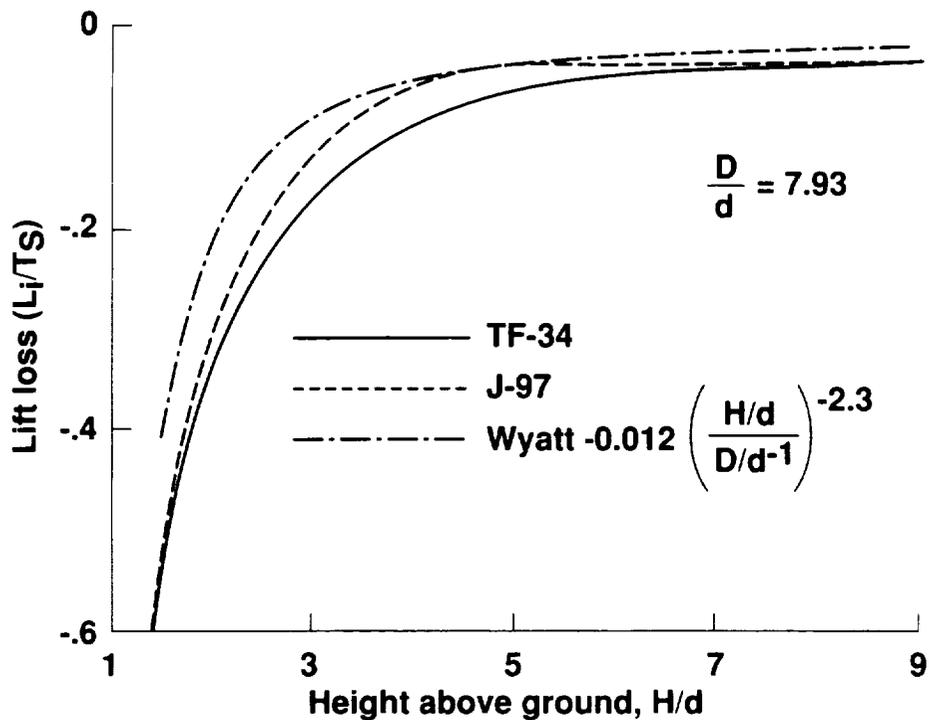


Figure 12. Hover induced lift in ground effect for two full-scale engines and an empirical result from small-scale experiments.

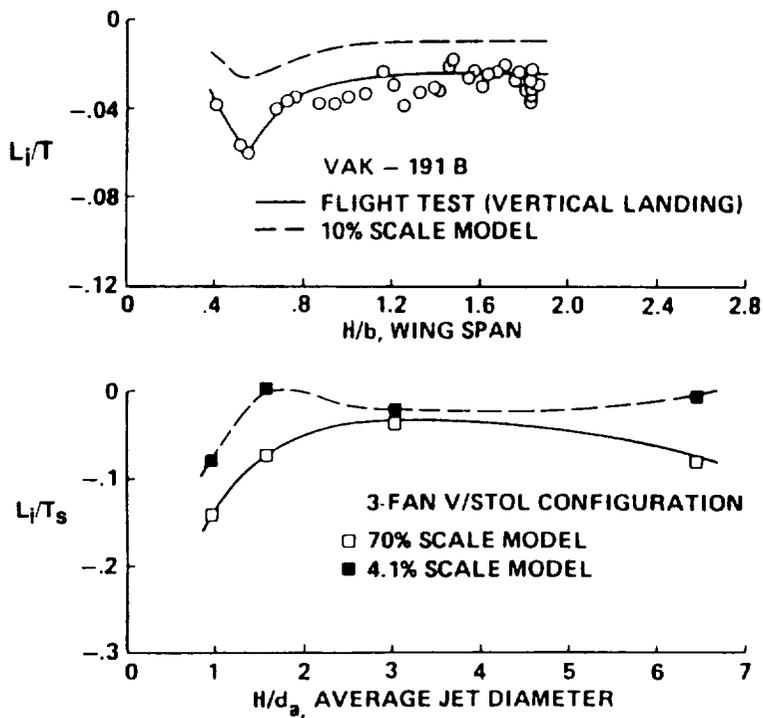
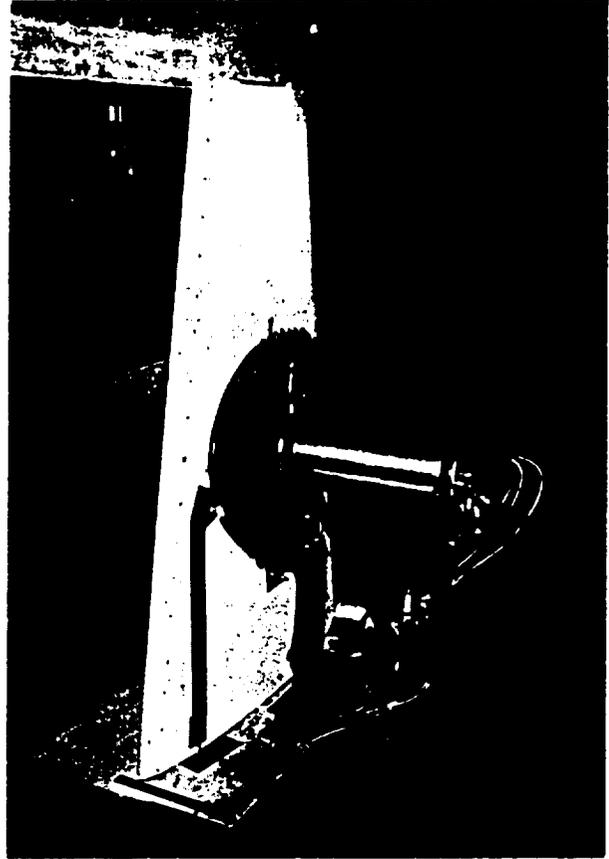


Figure 13. Small- and large-scale comparisons of ground effect for complete aircraft configurations.



With inlet vanes.



With exit vanes.

Figure 14. 1958 arrangement for semispan fan-in-wing model in the Ames 7- by 10- Foot Wind Tunnel.

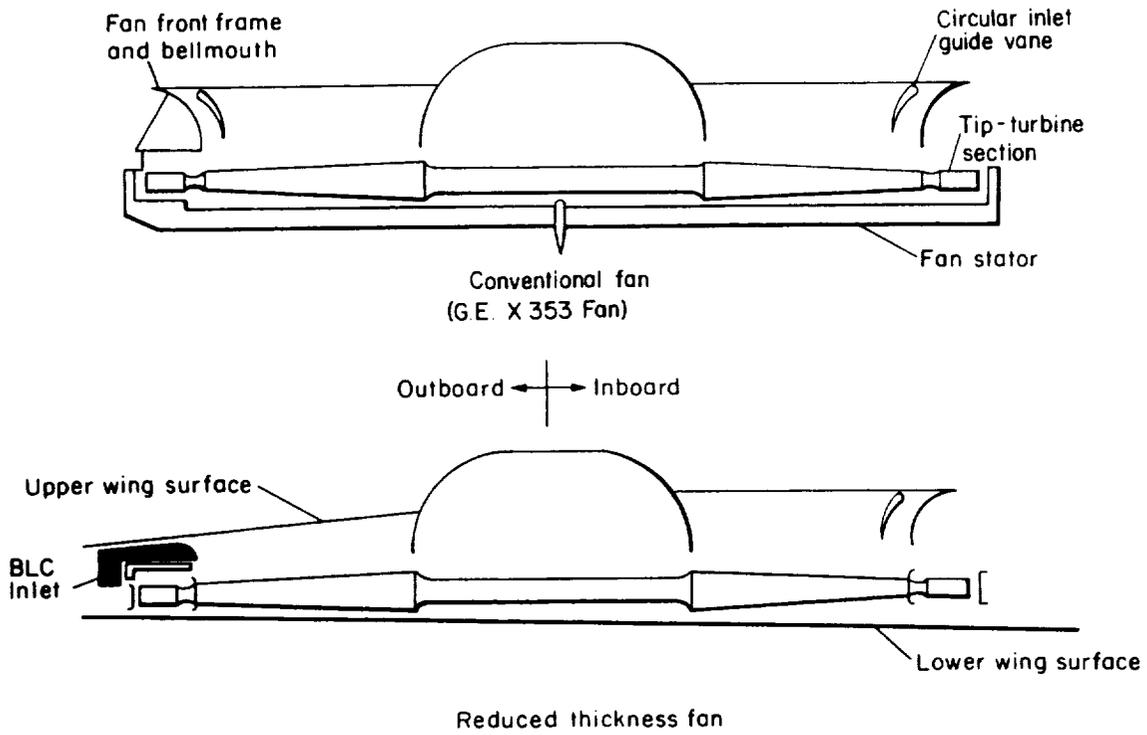


Figure 15. Cross sections of the conventional and modified statorless fan.

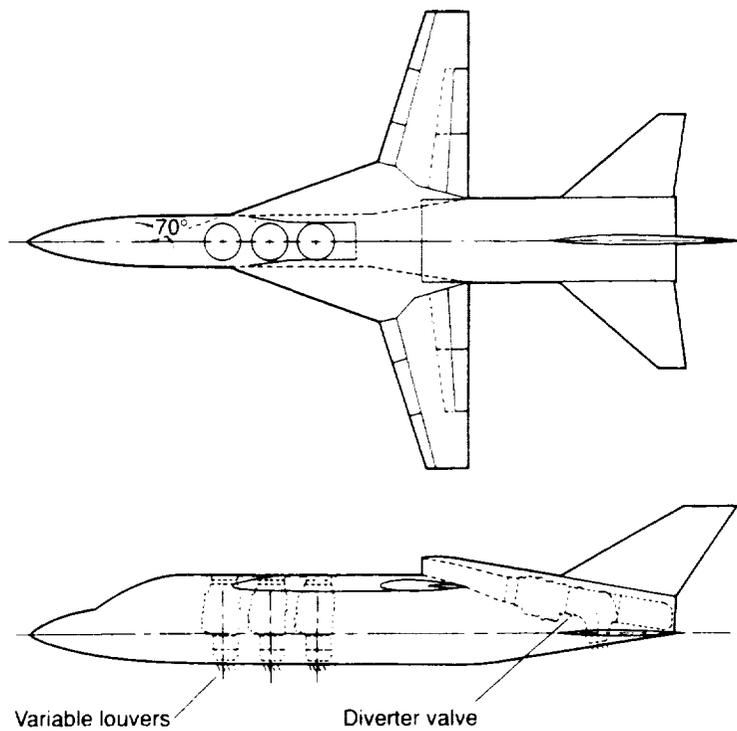


Figure 16. Large-scale lift/lift-cruise model

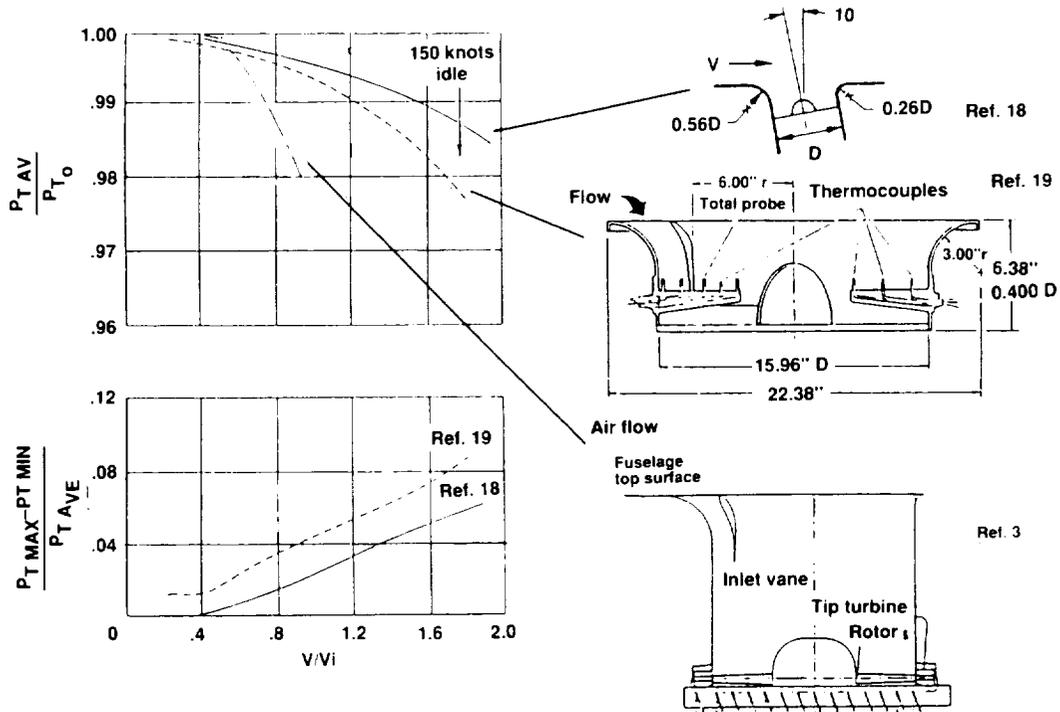


Figure 17. Comparison of performance of three left engine inlets.

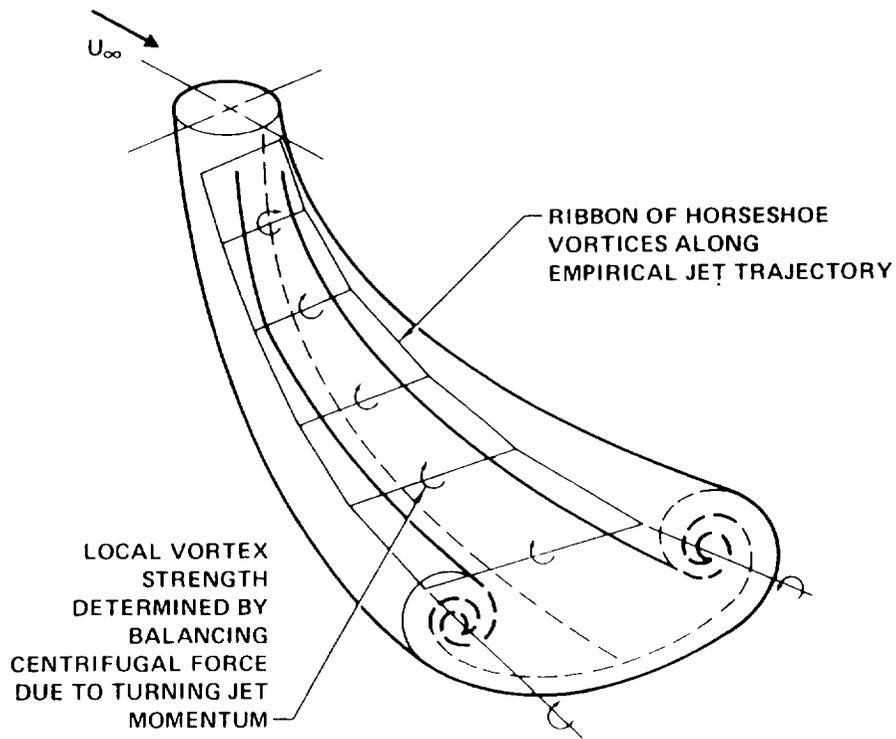


Figure 18. Typical model of a jet-in-crossflow.

MODEL	TYPE		WING ASPECT RATIO	SWEEP OF QUARTER CHORD LINE	TAPER	$\frac{A_1}{S}$	$\frac{D}{C}$	$\frac{D}{b}$	$\frac{X}{C}$	REFERENCE
1	Fan-in-fuselage		5	0°	.5	.084	.552	.147	.25	3
2	Fan-in-wing		3.5	16°	.5	.099	.428	.269	.392	14
3	Fan-in-wing		3.11	16°/25°	.32	.147	.48	.349	.43	9
4	Fan-in-wing, 6 fans AFT Fan-in-wing, 4 fans AFT Fan-in-wing, 2 fans AFT Fan-in-wing, 6 fans forward		3.43	20°	.47	.115 .078 .038 .115	.292 .268 .245 .292	.505 .336 .168 .505	.42 .43 .44 .322	NASA TN D-4233
5	Fan-in-wing		2.2	52.4°	0	.12	.335	.363	.63	16
6	Tandem lift fan Fan-in-wing, 2 fans AFT Fan-in-wing, 2 fans forward		5.8 (basic) 3.44 (gross)	35°	.3	.073 .036 .036	.796 .398 .398	.164 .164 .164	.286 1.24 -.657	29
7	Folding lift fan Rotating cruise fan		5.8	35°	.3	.123	—	—	—	29
8	Tandem podded lift fan 2 fans forward 2 fans AFT		5.8 (basic) 4.04 (gross)	35°	.3	.086 .043 .043	.946 .473 .473	.164 .164 .164	— -.80 1.16	NASA TN D-6234
9	Lift-cruise fan 2 fans forward (podded) 2 cruise fans AFT		5.8 (basic) 4.4 (gross)	35°	.3	.094 .047 .047	— .473 —	.164 .164 .164	— -.80 —	NASA TM X-62151
10	Low wing tandem lift fan 2 fans forward (podded) Fan-in-wing, 2 fans AFT		5.6 (basic) 3.7 (gross)	35°	.3	.080 .040 .040	— .473 .370	.165 .165 .165	— -.80 1.19	NASA TM X-62102
11	Low wing, 2 lift Fans forward 2 lift/cruise fans AFT		8.14	23.5°	.23	.115 .057 .057	— .48 .48	.134 .134 .134	— -2.56 2.61	NASA TM X-62231
12	1 fan forward 2 lift/cruise/'D' deflector		4.5	25°	.3	.101	—	—	—	NASA CR-152181
13	2 tilting lift fans		7.6	0/10	.47	.12	—	.101	—	20

Figure 19. Geometry of large-scale lift-fan-powered models tested in the 40- by 80- Foot Wind Tunnel.

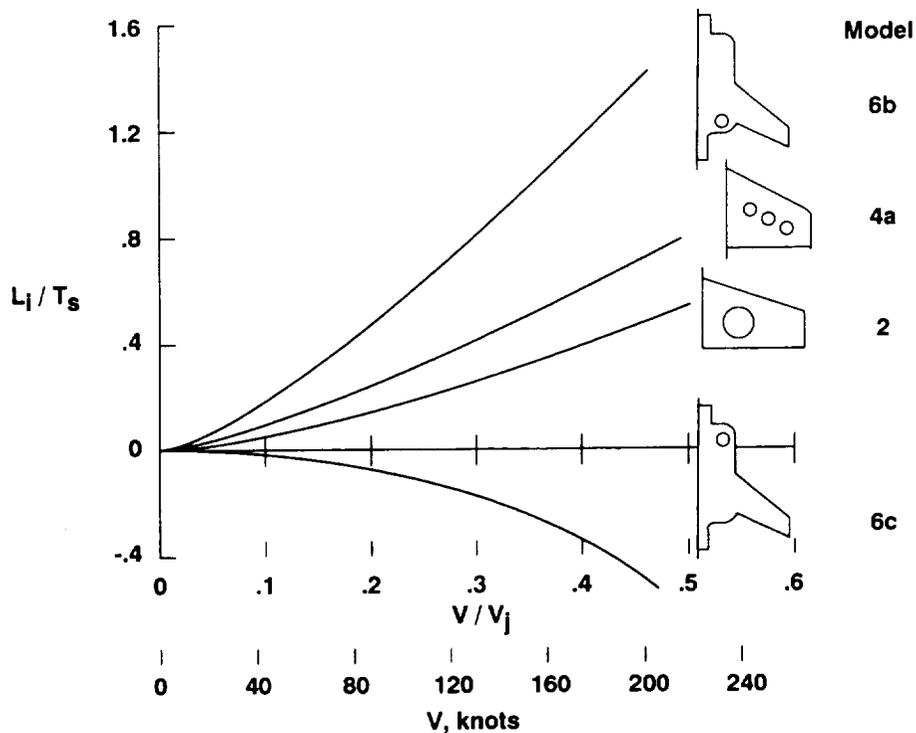


Figure 20. Induced lift variation with airspeed for several fan-in-wing configurations.

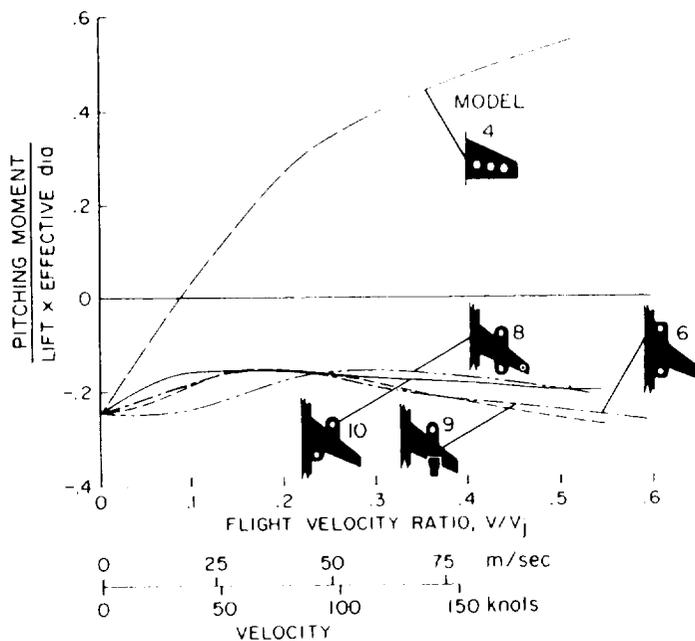


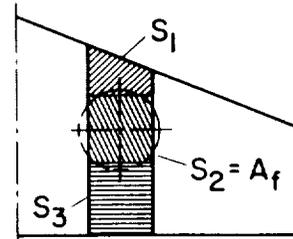
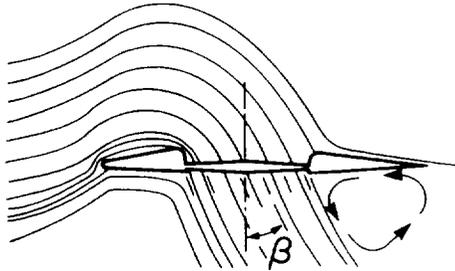
Figure 21. Pitching moment variation with airspeed for several fan installations.

SCHEMATIC FOR INDUCED LIFT CALCULATION

THE FLOW FIELD WITH FAN OPERATING

$$\delta_j = 90 - \beta$$

$$\frac{L_i}{T_s} = \frac{V^2}{V_{js}^2} \frac{C_L \delta_1}{4\pi A_f / S} \left[\frac{C_L}{\delta_j} \cdot \delta_j \frac{S_1}{S_{2d}} - \left(\frac{V_j}{V} \right)^{3/2} \frac{S_3}{S_{2d}} \right]$$



AREAS FOR INDUCED LIFT CALCULATION

Figure 22. Schematic for induced lift calculation.

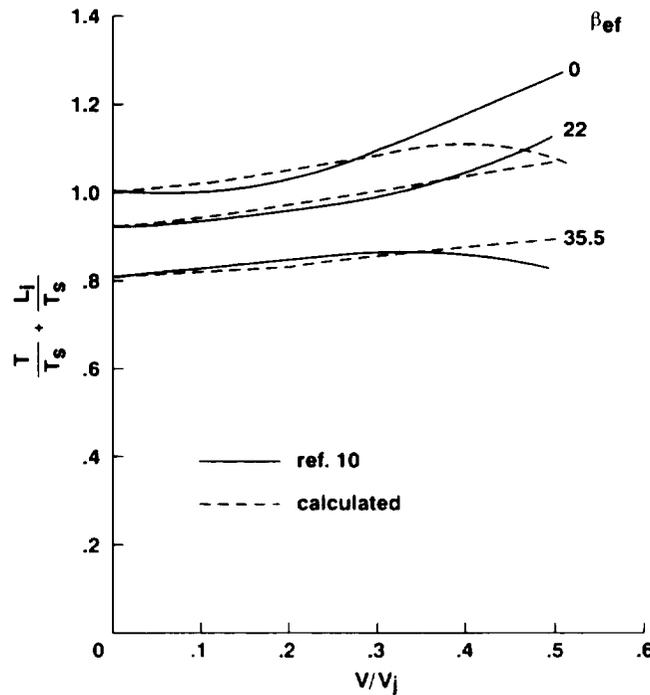


Figure 23. Calculated and measured variation with airspeed for three exit louver angles.

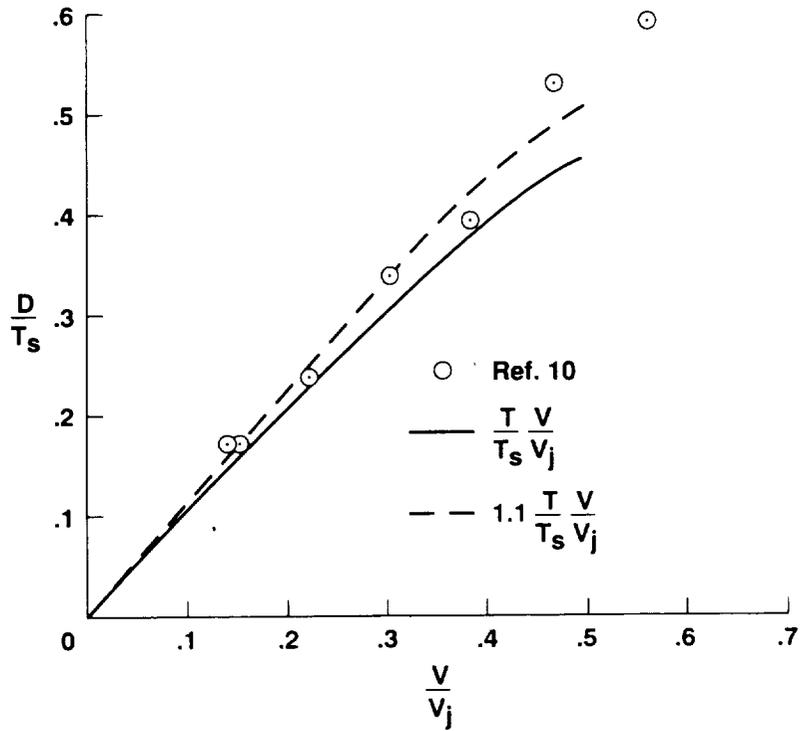


Figure 24. Calculated and measured variation of drag with airspeed.

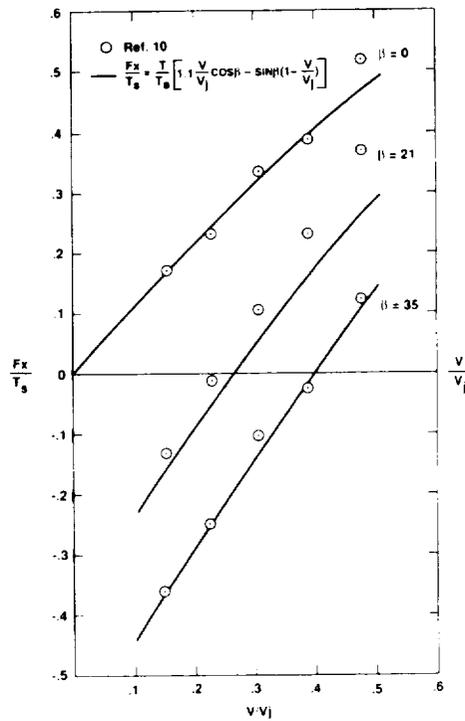


Figure 25. Calculated and measured horizontal forced with a lift fan operating with three exit louver angles.

Doak VZ-4 Ducted Fan Wind Tunnel Tests

Figure 26 is a ducted fan on semispan in Ames 40 x 80. The fan had inlet guide vanes, fixed pitch blades (variably tested by manual set), and exit vane with flap. Figure of merit was 78%, decreasing as blade angle increased. Thrust for blade pitch was 80 lb/deg; for inlet guide vanes used on the VZ-4, 12 lb/deg. These inlet vanes were 15% as effective as blade pitch for lateral and height control near hover.

The exit vane overcame high pitch-up moments caused by the tilted duct at forward speed. Figure 27 shows the setting of vane 10/flap 20 deg reduced maximum out of trim moment by 50%. Exit vanes reduce duct tilt in transition which helps control duct lip stall. Exit cascades, figure 28, were evaluated. Figure 29 shows, compared to vanes off for the original Doak duct, one cascade tested increased descent rate by a factor of 2.5. One lesson from this 1960s work was that exit vanes are effective for alleviating the common V/STOL problems of descent rate capability, deceleration in steep approach, and air braking needed to approach hover.

Wind Tunnel Tests of X-22 Lift/Cruise Fan Aircraft Model

Section includes 0.57 scale aircraft model, and an isolated full-scale X-22 fan. Emphasized is the lesson that adequate margins must exist during descents; deceleration margin of -0.05 to -0.10g, plus 2 to 3 deg descent angle margin for maneuver. For the basic configuration, maximum descent angle was -6 to -10 deg. With margins of -.05g and -3 deg, descent was reduced to 0 to -2 deg, which would be of little practical use for terminal area operations. Other findings were reasonable ground effects, need for a good wing for L/D, higher pressure ratio fans to reduce cruise fuel consumption, and benefits from variable blade pitch.

Avrocar

These wind tunnel tests, figure 30, complement flight section in Reference 1. Figure 31 shows the effect of ground height on lift, which increased 250% as height decreased from h/D values of 1.0 to 0.15. Since these tests, this ground effect phenomena has been utilized by air cushion machines. Other findings or lessons were (1) lower power required at forward speed in ground effect compared to out of ground effect, hence the resulting low speed of the Avrocar, (2) large inlet momentum drag and high duct loss were two reasons why out of ground effect forward speed would have been limited to 59 knots at 4500 pounds, (3) Avrocar had neither forward thrust, nor pitch control, nor lift to fly above 70 knots out of ground effect at design weight.

General Electric Lift/Cruise Fan - Wind Tunnel Tests

Tests were conducted of a 1.1 pressure ratio ducted lift/cruise fan, 62.5 in dia, driven by exhaust of a J-85. Exit area was varied for effects on static and forward speed performance. Results show the need for a variable area exit nozzle for a fan with fixed blade angle instead of variable blade angles. Presented are the effect of duct external drag and duct stall. With margins, descent performance was less than -10 deg for all speed conditions and duct angles of 50 deg or more. Once duct lip stall occurred, large increases in rpm were necessary to unstick the lip.

Reingestion of V/STOL Lift-Engine Fighter Models

Models were powered by J-85s, with internally fixed lift engines, figure 32, (see complementary results in Reference 2), or with retractable engines. All exhibited excessive thrust loss and compressor stall with thrust vectored 90 deg, i.e. vertically. Of three exhaust nozzles tested with the fixed engine, figure 33, the slotted nozzles produced less gradient and average inlet temperature, thus less lift loss than the conical or bifurcated nozzles. It was demonstrated on the retractable engine model, and believed true on the other model, that vectoring lift engines to a small forward angle and lift/cruise engines aft to balance the aircraft alleviated exhaust gas ingestion and thrust losses. The aircraft could takeoff and land with decelerating approaches while surrounded by exhaust but relatively free of ingestion effects and losses. In addition to that lesson learned, pointed out is that results may be applicable to aircraft with the higher pressure ratio lift fans, and that the technique might also be used to alleviate suck down.

Grumman-698-111 Tilt Nacelle V/STOL Model

Figure 34 is the powered model in the 40 x 80. Nacelles with lift/cruise fan engines tilt forward of the wing. The tilting nacelles during transition change center-of-gravity alot (about 9 in at landing weight). This affects control power available after trimming moments due to c.g. shift. The magnitude of c.g. shift is very unusual for a V/STOL aircraft. Figure 35, descent performance and inlet fan stall, indicates trimmability over a wide range of nacelle deflection, angle of attack, velocity, and flight path angle. However, large nose up pitching moments reduce control available for maneuver to 50% of acceptability, figure 36. The large pitch up is mostly due to the long inlet and its height above the c.g., and to the large area of unprotected wing center section over the fuselage. One proposal was to reduce inlet length by 1 ft to achieve sufficient reduction of pitch up moment. However, during ground effect static tests, lack of ingestion and thrust losses was attributed to some degree to the high location of the inlet.

Fan-in-Wing Stall Boundaries

The fan-in-wing as in the XV-5 was subject to fan stall as well as wing stall that affected fan stall and vice versa. Such effects were examined in the wind tunnel using the 5.2 ft dia fan in different wings. Figure 37 shows the variation of tip speed ratio for stall with angle of attack. Shown is the aircraft flown level at a -10 deg descent angle at 70 knots, and flown parallel to the -10 deg descent path. At 10 deg wing angle of attack, for the deck level approach the margin to stall is small--2 to 3 deg angle of attack and 10 knots speed --which would be critical to gust or maneuver requirements. With deck parallel, 12 deg angle-of-attack margin exists and a factor of two up to 150 knots could be flown before reaching the stall boundary at an angle of attack near 0 deg. Lesson learned: the technique used for approach has much to do with fan-in-wing stall margins.

Conceptual Design Considerations

One design study discussed is on the Lift Fan Research and Technology Aircraft (LFRTA). Figure 38 shows modified T-39s, a McDonnell gas-coupled and a Boeing shaft-driven design. Figure 39 shows two types of shaft-driven systems. Findings or lessons from the LFRTA include the following.

- * Need for design guidelines specifically for technology demonstrator aircraft. The paper presents one such publication. Each of the many subjects in it is a lesson learned.
- * Shaft-driven was 7% more efficient than gas-coupled, but its higher weight offset some of the difference.
- * Gas-coupled had fixed blade pitch whereas shaft-driven had variable which offered advantages discussed later.
- * Problem for shaft-driven 1975 LFRTA was fatigue life and qualification of gears. Figure 40 shows gear tooth bending stress versus pitch line velocity. Pitch line velocities are high compared to most gears for helicopters of that era.
- * Gas-coupled needed development of large ducts and high temperature valves. For small aircraft volume available for ducts is not sufficient.

Points made for the LFRTA or other designs include:

- * Compared to fixed fan blade pitch, variable pitch offers (1) faster response, (2) less fan thrust loss for large control inputs, (3) much better cruise performance, and (4) potential for reverse thrust at low speed of one fan to balance multifan aircraft for one fan out safe flight.
- * Horizontally mounted lift fans with exit louvers at -30 deg produce deceleration forces that are much greater and more effective than those from simply deflecting or tilting the cruise fan or engine thrust.
- * Fans in fan-in-wing cause penalties in wing weight, thickness, and volume for fuel; but horizontal lift fans have merits as stated above, and statorless fans can alleviate thickness problem.

Technology Utilization for Conceptual Design Studies

In his introductory remarks, Mr. Cook says his paper includes "design integration problems - - including lessons learned during more recent conceptual design studies related to a small executive V/STOL transport aircraft". Mr. Cook has devoted a portion of 10+ retirement years to conceptual design of lift-fan V/STOL aircraft. For creditable design, one must understand the lift-fan technology that has been developed over the past 35+ years, where to find it, and how to use it. This Technology Utilization section is a 4-page outline covering subjects that must be addressed. The entire outline could also be called "Lessons Learned".

The outline is organized into 11 topics: horizontally mounted lift fans, lift/cruise fans, control systems and simulation, flight tests, structural weight and materials, lift plus lift/cruise fan model wind tunnel tests, conversion, control and stabilization systems, technology demonstrator aircraft, conceptual design tradeoffs, and potential military use. Subsection I follows:

- I. Horizontally mounted lift fans (Hickey & Kirk)
 - A. Data from static and wind tunnel tests for following:
 - 1. Fan sizing and thickness
 - 2. Wing sizing function of fan size
 - 3. Hybrid configuration-effect of fan downwash on aft wing
 - 4. Fan induced lift, drag, and pitching moments
 - 5. Determination of lift fan stall boundaries with cross flow and angle of attack
 - 6. Inlet requirements for vane, and closure door or vanes
 - B. Geometric characteristics of lift fans dependent on number of fan blades and blade area

Lift-fan technology is such that technology demonstrator aircraft will precede production aircraft. Thus one subject of interest is subsection IX (paraphrased herein).

- IX. Technology demonstrator aircraft (TDA)
 - A. Geometric size, aerodynamic shape and details, would be same or close as possible to prototype
 - B. Structural strength of aircraft and components would be designed for 235 rather than 350 knots, corresponding to dynamic pressures of 182 rather than 405 lb/sq ft
 - C. Design for 2-place with instrument package for flight to prove technically, then demonstration flying, then as 3-place with $\frac{1}{2}$ fuel load of production aircraft
 - D. Simplifications that are weight and cost effective, resulting in TDA weight 22 to 25% less than production
 - 1. Lift and lift/cruise fans designed for final thrust, but flown on TDA initially at 75%, thus requiring lower initial power requirements as well
 - 2. As development testing of fans was completed to design, gradually increase gross weight to production value.

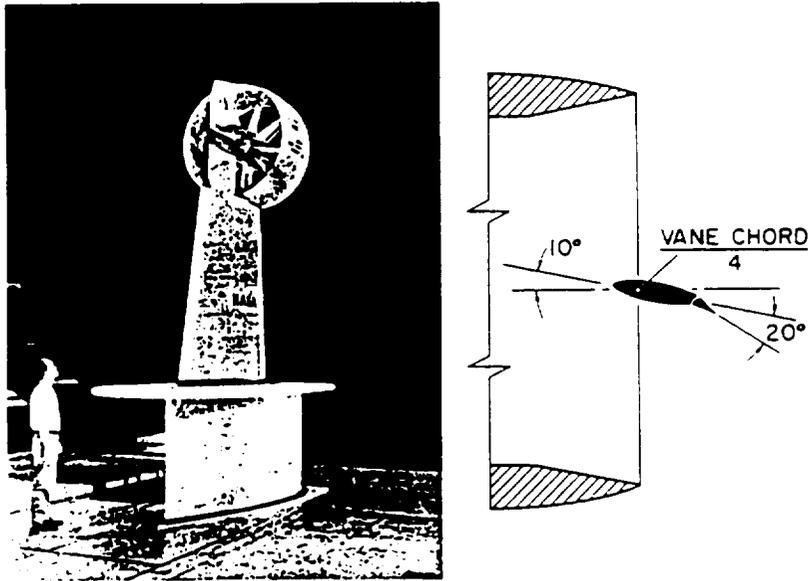


Figure 26. Model with duct exit vane.

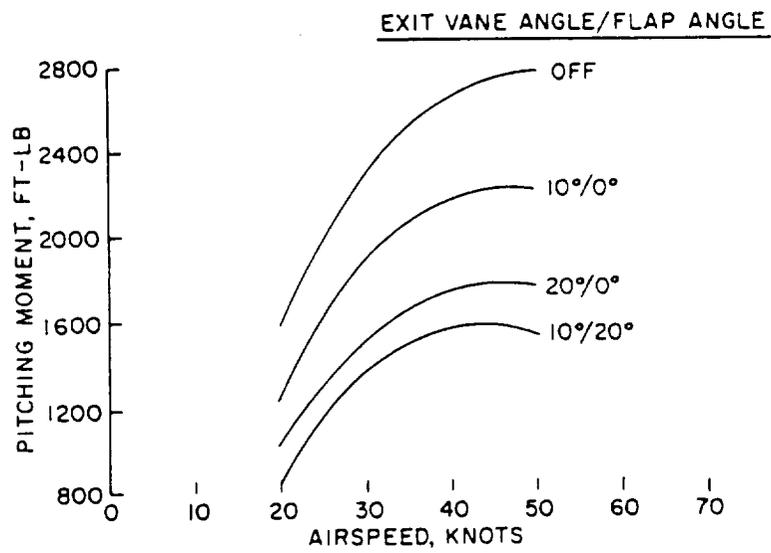


Figure 27. Reduction in pitching moment due to duct exit vane deflection.

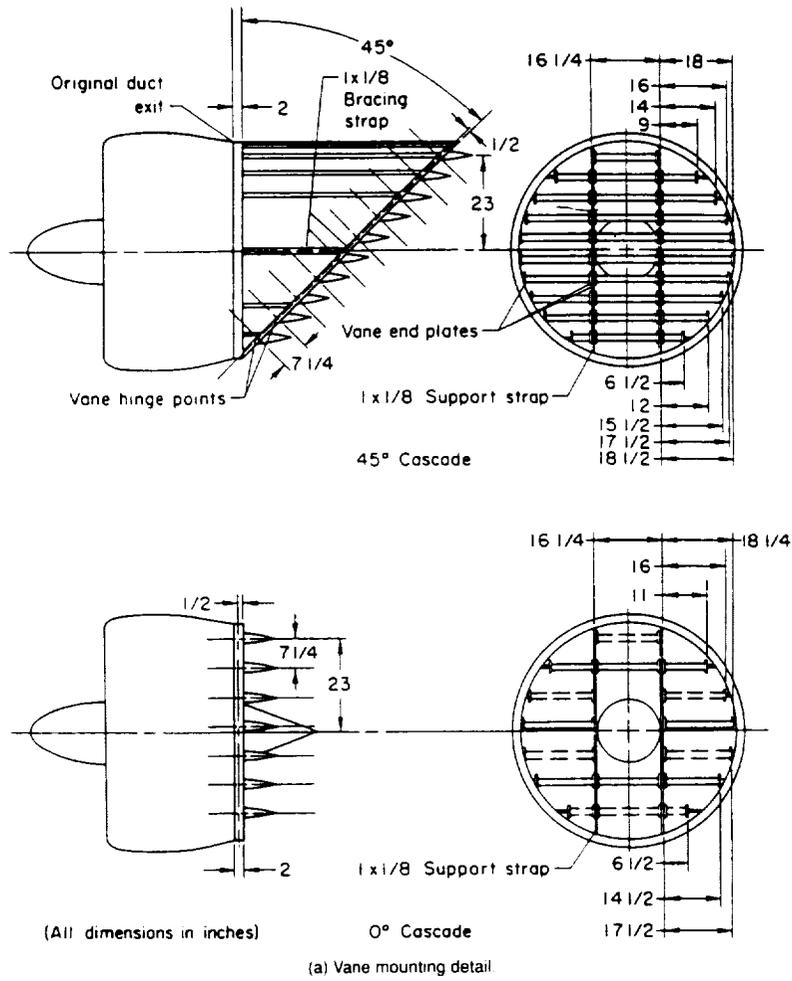


Figure 28. Exit vane dimensions and arrangement.

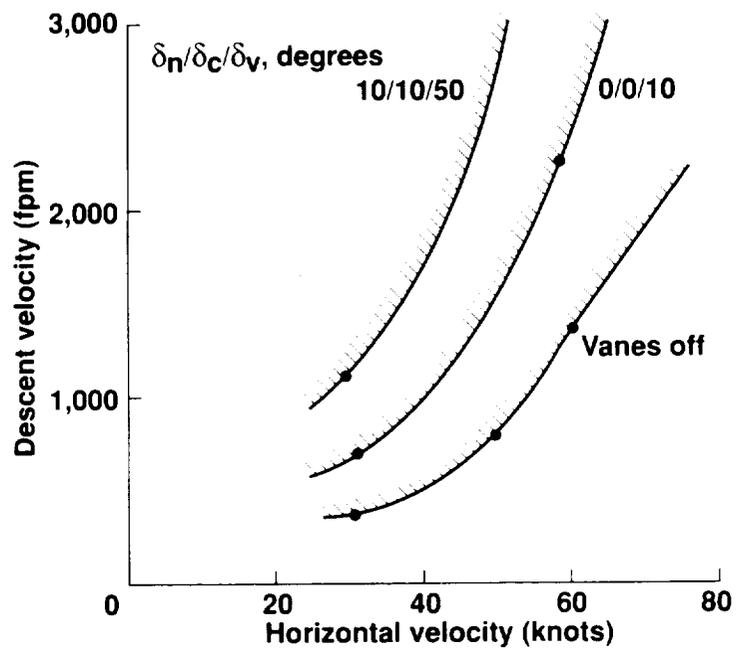


Figure 29. Descent velocity boundary due to stall of the upstream duct lip for the vehicle at 0 deg wing angle of attack using the 0 deg cascade with a vane chord-to-gap ratio of 0.83.

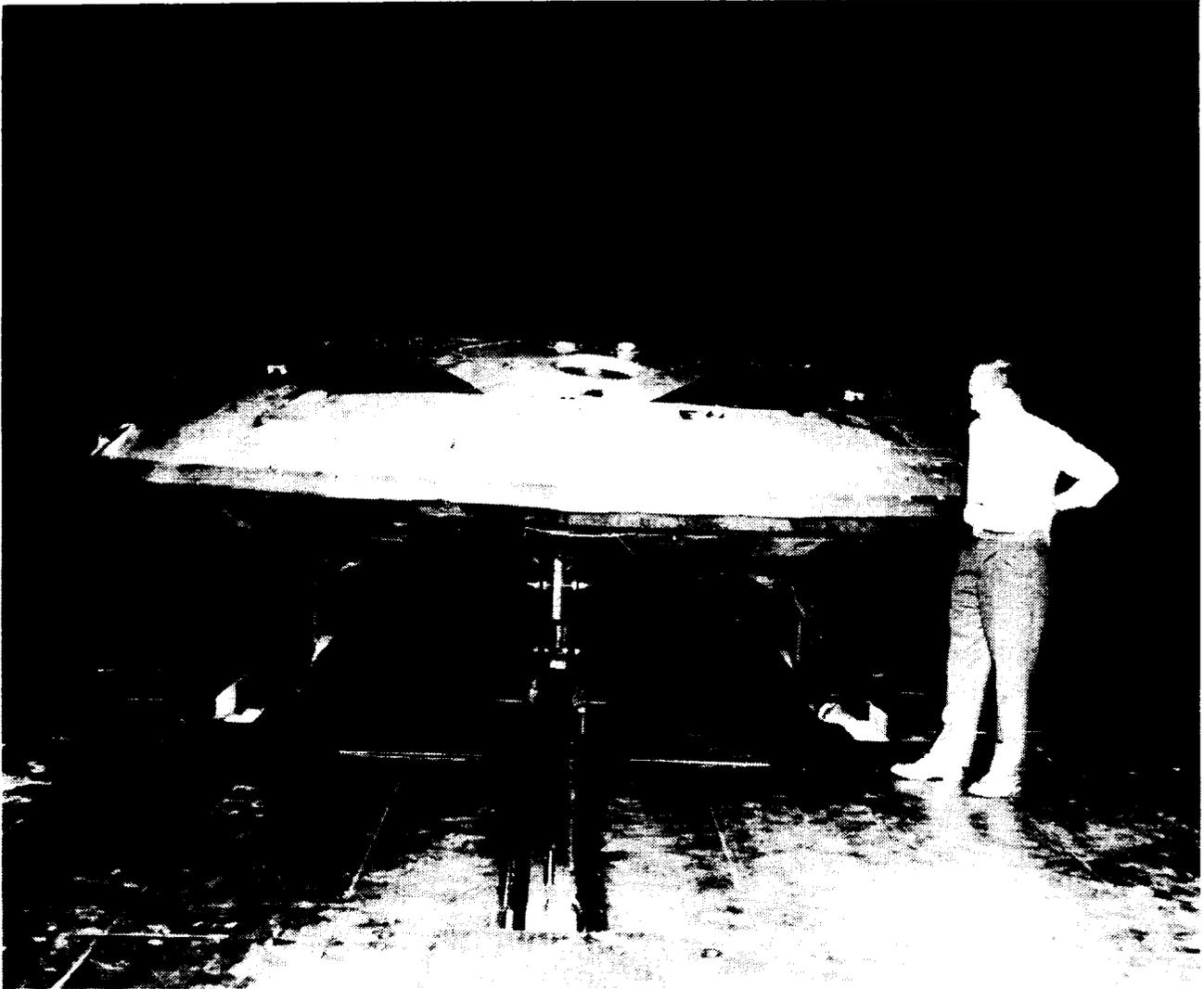


Figure 30. Rear view at minimum test height.

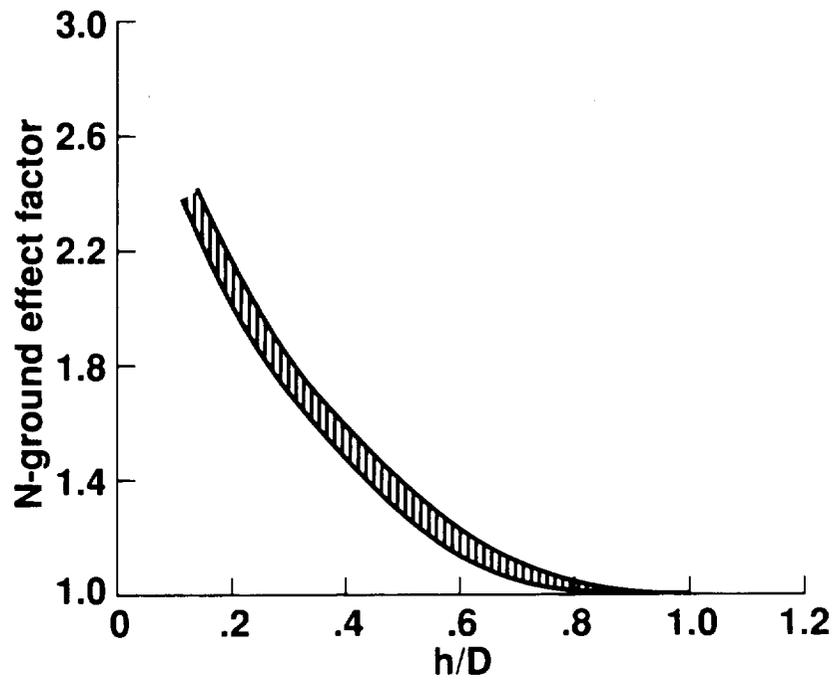


Figure 31. Variation of ground effect with height to diameter ratio.

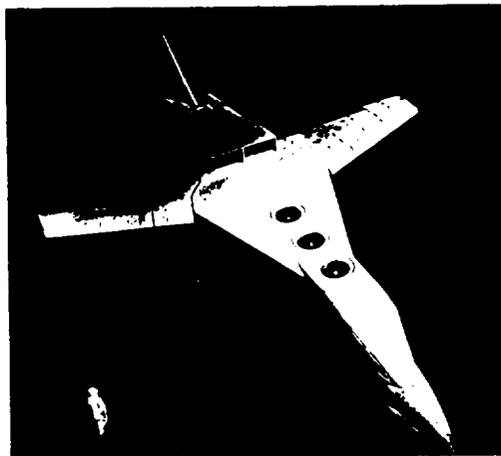


Figure 32. Lift engine model mounted in wind tunnel.

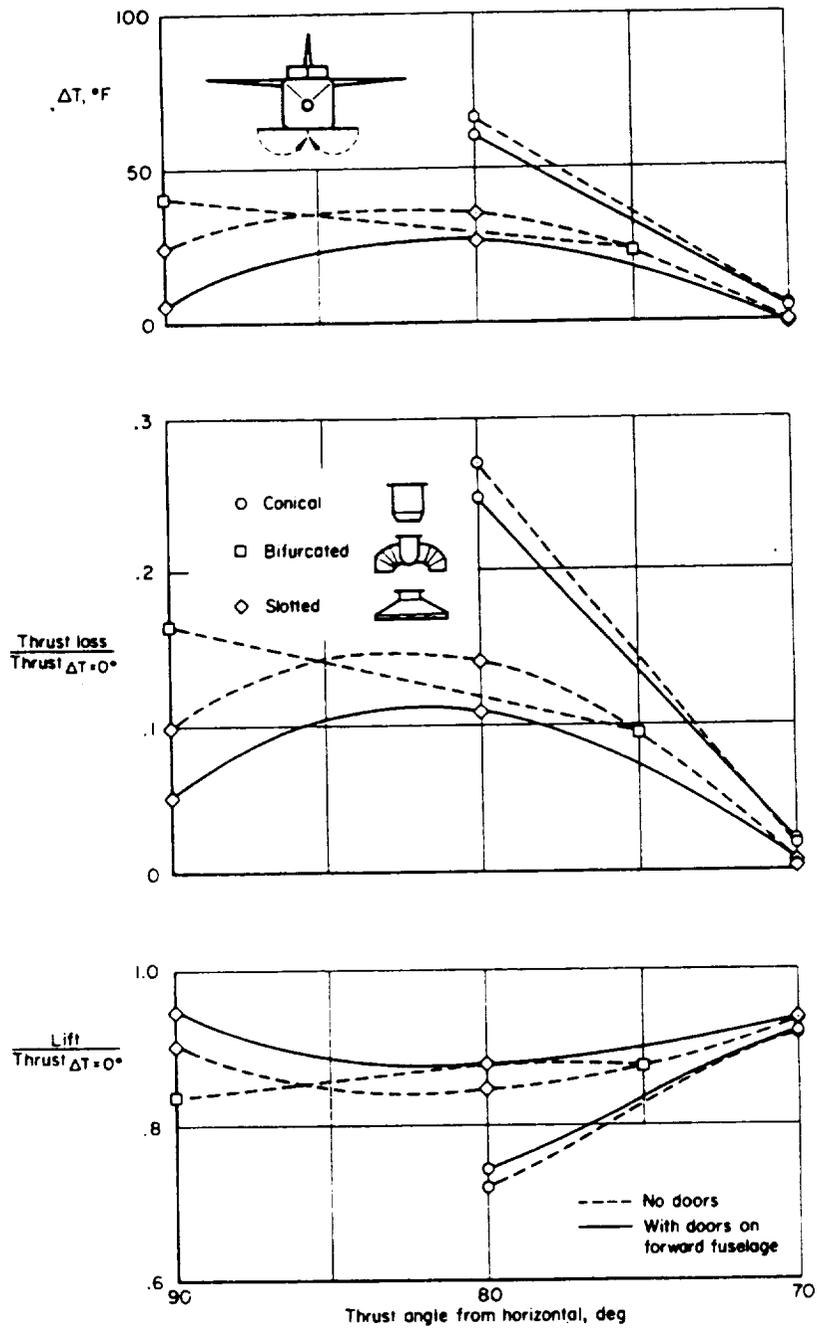


Figure 33. The effect of exhaust vectoring on temperature rise and thrust loss; internally fixed configuration, H/D = 5.0.

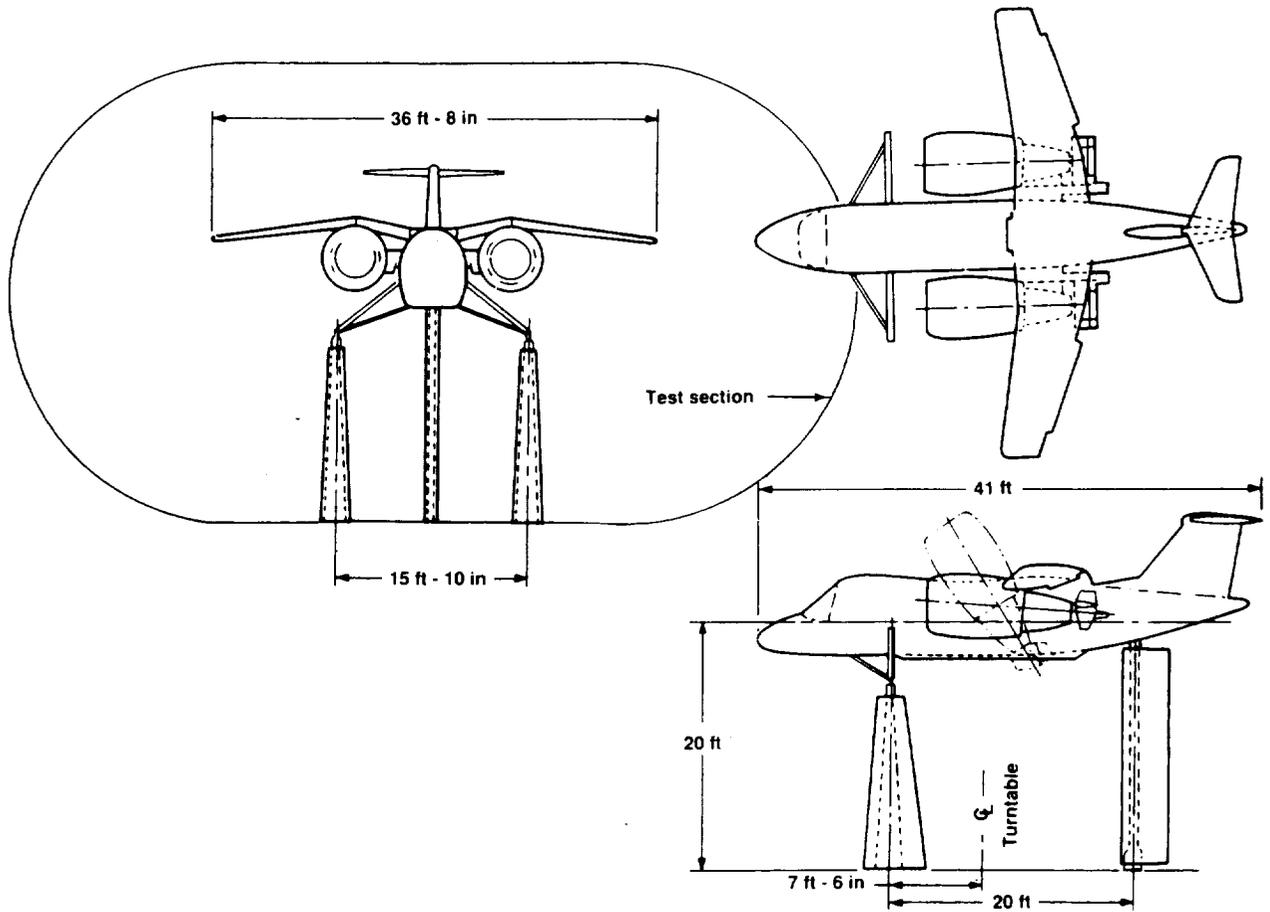


Figure 34. V/STOL model in 40- by 80- Foot Wind Tunnel.

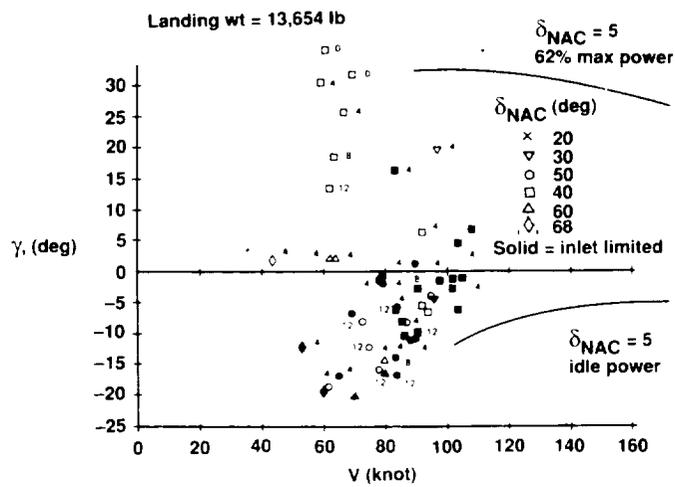


Figure 35. Trimmed performance.

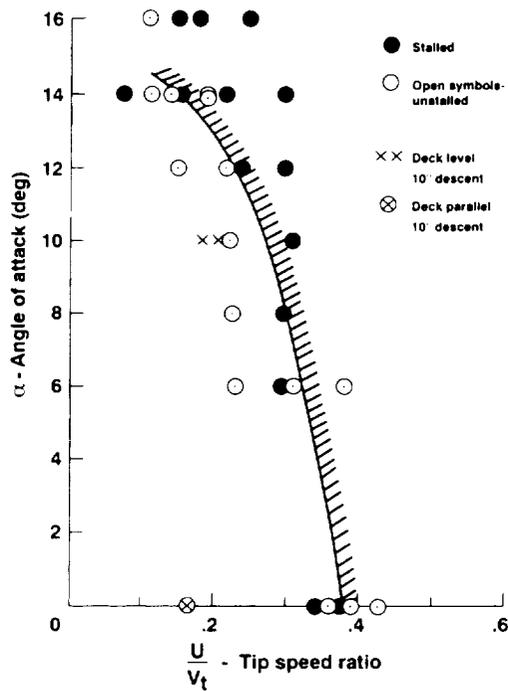
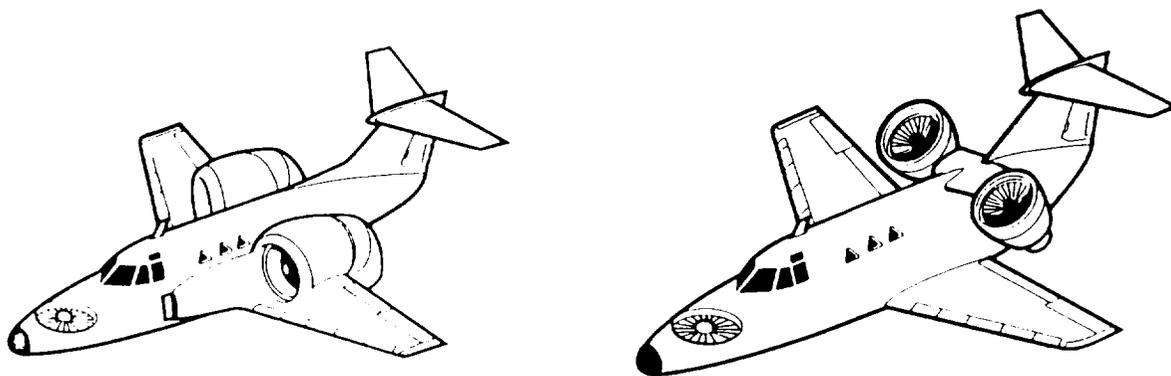


Figure 37. Effect of angle-of-attack on tip speed ratio stall boundaries.



- THREE FANS
- 110,000 TO 130,000 N (25,000 TO 29,000 lb.) VTOL GROSS WEIGHT
- 42,000 N (9,500 lb.) USEFUL LOAD

Figure 38. T-39 modification.

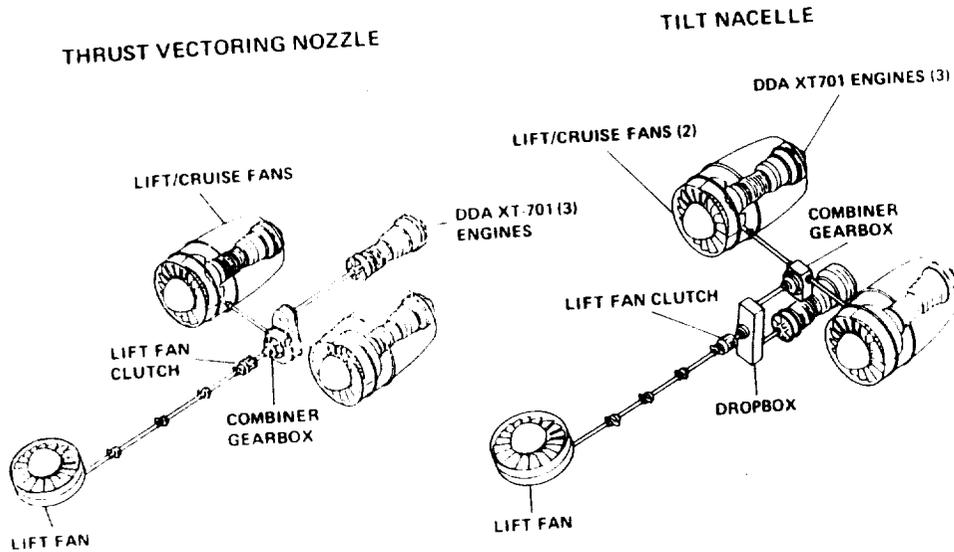


Figure 39. Shaft drive systems.

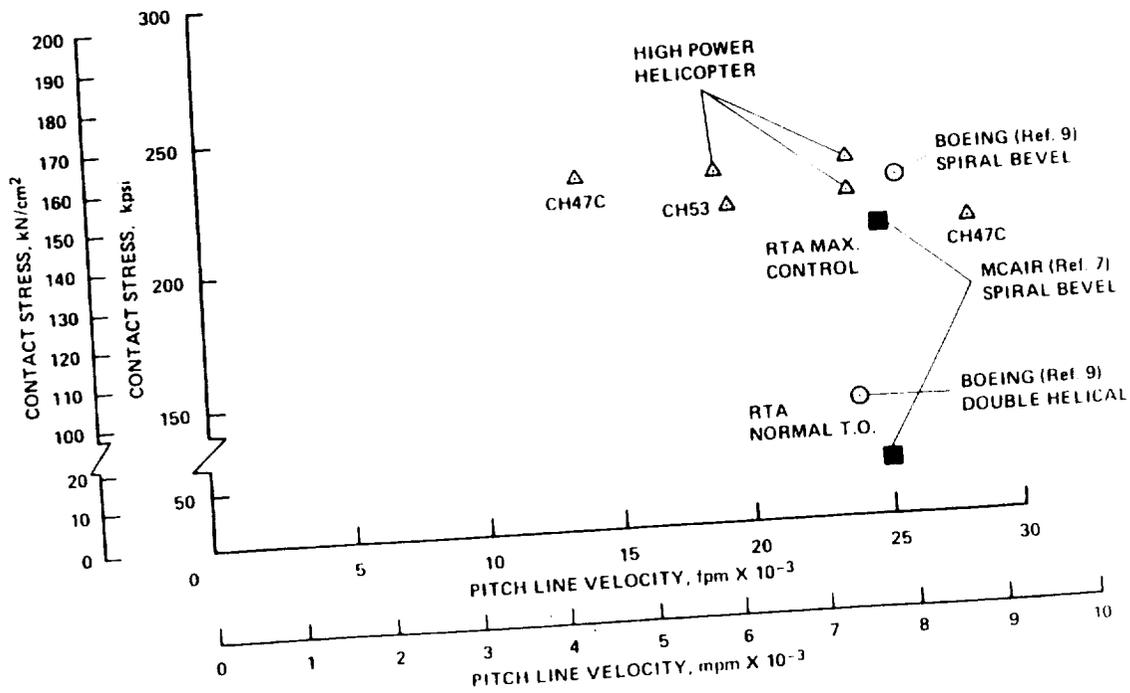


Figure 40. Effective pitch line velocity on stress levels . . . contact.

Summary of the Technical Paper by Franklin, Reference 4

Initial sections concern V/STOL lift fan research transport designs of the 1970s. Presented for four contractual designs are aircraft description, control effector concepts, flight control modes, control power, dynamic response of fan thrust and more. From moving-base simulations, presented are pilot evaluations of flying qualities and control characteristics, showing a preponderance of "Satisfactory" ratings when appropriate control modes were chosen. Some specific comments worth noting were (1) a preference for thrust deflection to control longitudinal translation in hover at constant pitch attitude, as opposed to modulating attitude, (2) preference for thrust deflection rates of 20 to 25 deg/sec for transition (5 deg/sec was inadequate), and (3) a difficulty in maintaining control during low power descent due to loss of control authority.

Mixed-Flow Remote-Lift Aircraft Design

Figure 41 shows the mixed-flow remote-lift STOVL fighter aircraft concept, used for following simulation program. The aircraft's size is comparable to that anticipated for a STOVL Strike Fighter (SSF), and use of propulsive and aerodynamic controls is similar. Generalized NASA results may be applicable to future SSF designs. Propulsion features include mixed fan and core streams ducted to lift nozzles or to thrust deflecting cruise nozzle, ventral nozzle diverts some mixed flow for pitching moment to counter that of lift nozzles, deflected lift nozzle thrust for longitudinal force, deflected cruise nozzle for pitch and yaw, and for transition the flow is smoothly transferred between nozzles.

Pitch--symmetric empennage deflection, reaction control, thrust transfer between lift and ventral nozzles, vertical deflection of cruise nozzle. Roll--ailerons, lateral thrust transfer for differential lift nozzle thrust. Yaw--differential empennage, reaction control, lateral cruise nozzle deflection. Longitudinal force--thrust transfer between lift and cruise nozzles, deflection of lift nozzle thrust. Height control--thrust. For transition either attitude or flightpath stabilization and command augmentation system (SCAS) was available, and a heads-up display (HUD).

Control Mode Evaluations

Figure 42a shows pilot assessment for decelerating transition under instrument conditions to a breakout at 100 ft. Unlike for attitude SCAS alone, with attitude-plus-flightpath SCAS the pilots managed the entire transition with minimal effort. Figure 42b is for vertical landings on an airfield, ceiling 100 ft, visual range 1200 ft, visual condi-

tions for landing. Unlike for attitude SCAS, for attitude-plus-velocity SCAS, control of vertical axis and of translational horizontal velocities was easy. Figure 42c is for recovery aboard ship. Assessments for attitude SCAS were poor. For attitude-plus-velocity SCAS, satisfactory ratings were obtained up to those high wind over deck (WOD) and sea state conditions that would limit air operations aboard ship for concerns other than aircraft flying qualities.

Control Usage

Presented are required pitch, roll, and yaw authorities from simulation of the STOVL design, including rationale.

Pitch control, figure 43: In transition, for maneuvering and effects of turbulence, control power of 0.20 to 0.25 rad/sec squared would provide for most demands. 0.14 to 0.27 would accommodate most demands for attitude SCAS for airfield vertical landings; with velocity command, vertical landing can require 0.17, independent of winds and turbulence. For shipboard landing, with attitude command alone, peak control usage is 0.38 rad/sec squared or less; with attitude-plus-velocity command SCAS, a requirement of 0.2 should suffice. Total available for conceptual STOVL was 0.42, with 0.08 to trim 34 kt wind, so pitch control was more than adequate.

Roll control, figure 44: Note that for this STOVL configuration in turbulence during transition, current criteria (References in figure 44) call for insufficient control. Based on this simulation, a roll control authority of 0.9 to 1.2 rad/sec squared would be necessary to satisfy demands for maneuvering and control in turbulence. Control use for airfield vertical landing is within referenced criteria, ranging from 0.2 to 0.4 in heavy turbulence for both attitude and attitude-plus-velocity SCAS. For shipboard landing, results agree with criteria for light winds, but not for high wind over deck conditions. Operation aboard ship with high WOD is limited by capability to recover to the deck rather than by aircraft controllability. And here is a case where attitude-plus-velocity SCAS required more control authority than attitude SCAS alone. Total roll control available for the STOVL in basic configuration was 1.1 rad/sec squared, so it was necessary to augment the baseline with reaction control to handle high WOD for recovery to the ship.

Yaw control, figure 45: For transition and for airfield vertical landing, criteria all exceed these results by a significant degree. The disparity is likely attributable to good yaw stability augmentation and lower sensitivity to disturbances for recent STOVL fighter concepts compared to the collection of aircraft on which the earlier criteria were based. Total yaw control authority for this STOVL design was 0.28 rad/sec squared.

Thrust Transfer Rates

Ability to achieve adequate rates of thrust transfer between propulsion components for pitch and roll control is an important aspect of control system dynamic response.

Pitch control, figure 46: Most significant control rates are for shipboard landing. Maximum rates of 3 to 6 klb/sec with longitudinal velocity command SCAS occur at highest WOD. Thrust transfer rates are also expressed in time rate of change of control power for this aircraft, which can be used to define the relationship between peak control usage and the effective bandwidth of control that can be achieved without encountering the control rate limit. For example, a maximum thrust transfer rate of 2 klb/sec, which corresponds to a rate of change of angular acceleration of 0.5 rad/sec cubed, and a peak control usage of 0.05 rad/sec squared would imply a rate free control bandwidth of 10 rad/sec. For pitch (and roll) control system designs, variations in bandwidth within a range that provided satisfactory flying qualities for the low speed flight tasks did not have a significant influence on peak control rates or usage. Designers have considerable latitude in choice of control bandwidth while avoiding excessive control use or actuation rates. (Paper also covers thrust transfer rates for roll control.)

Thrust Control

One section is on influence of ground effect and hot gas ingestion, figure 47. Experiments were conducted on the vertical motion simulator (VMS) to evaluate in general these effects on thrust margin necessary to control height and sink rate during airfield vertical landings. The results were validated with specific simulation assessments with the YAV-8B. Boundaries are presented that define acceptable and unacceptable regions for combinations of mean ground effect and ingestion and thrust/weight ratio. The shape of the boundaries is established by height control out of ground effect for positive ground effect, on abort capability at decision height for neutral to moderately negative ground effect and ingestion, and on control of sink rate and hover position to touchdown for larger negative ground effect.

Another section is the influence of engine dynamics, figure 48. These data apply to manual control of thrust for vertical landing with attitude SCAS only. Shown is that a bandwidth of thrust response of the engine core of 4 to 5 rad/sec is sufficient to achieve satisfactory ratings for height and sink rate control. To a point, vertical landing is insensitive to maximum rate of change of core thrust, which is associated with engine acceleration limits imposed by maximum allowable temperatures in the core. Maximum thrust response rates from 25 to nearly 10 %/sec were tolerable for height control. At about 10 %/sec, thrust rate

limiting and loss of control were encountered on occasion for such slow acceleration. Deceleration rate limits are important to the ability to rapidly reduce thrust at touchdown, as well as to control vertical velocity in hover.

Accelerating Transition

Pilots' assessments for accelerating from hover to forward flight indicate that flightpath acceleration in excess of 0.13g is desired for fully acceptable capability. For 0.08g or less the aircraft is intolerant of abuse of control technique and forces the pilot to devote attention to coordination of attitude and thrust deflection control. Interpretation of minimum usable transition flight envelope can be obtained from figure 49. The constriction in the flight envelope with thrust deflection from 40 to 60 knots, represented by minimum longitudinal acceleration in level flight, or equivalently, minimum climb angle, is apparent.

Concluding Remarks

Each result from the research presented could be called a "lesson learned". The lesson from the sum of all results reviewed is that they provide the basis for a reassessment of existing flying qualities design criteria for this class of STOVL aircraft.

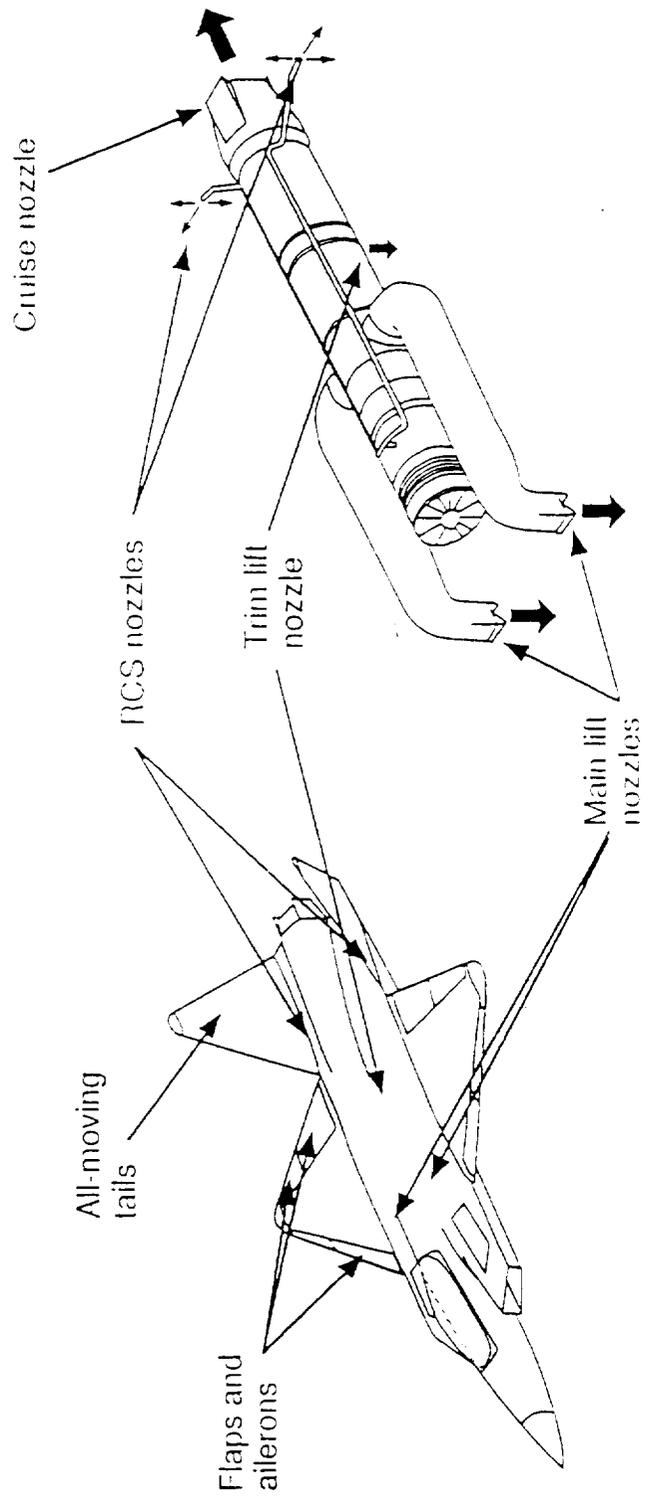
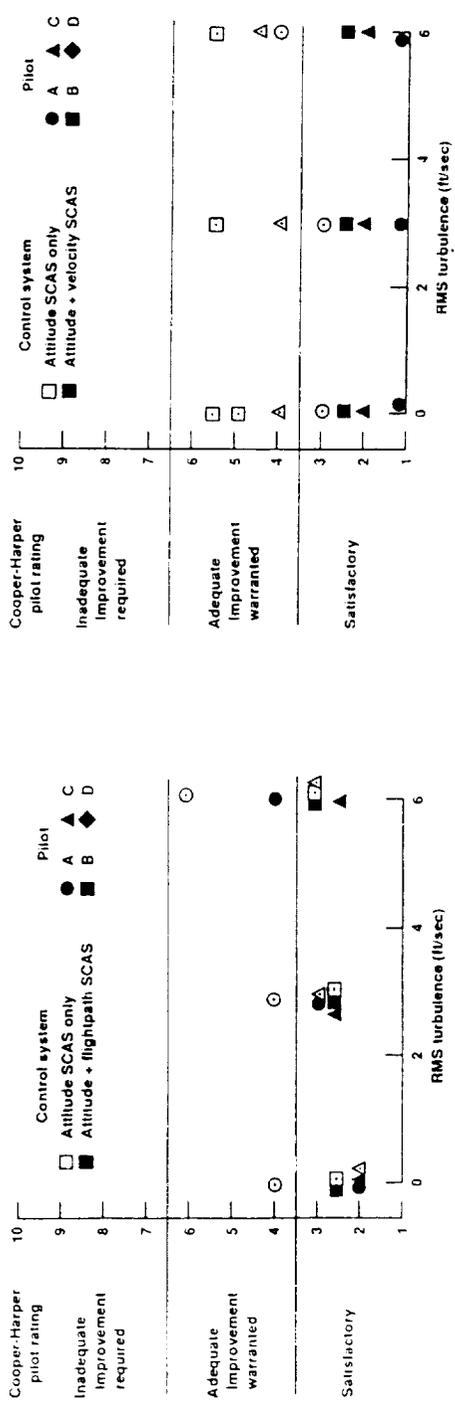
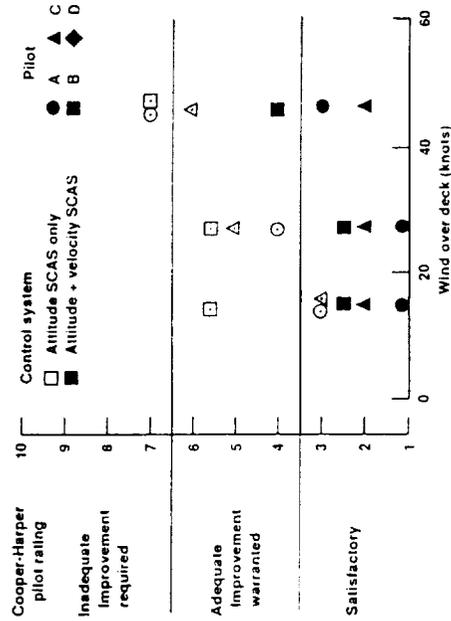


Figure 41. Mixed flow remote lift STOVL aircraft.



a. Transition

b. Airfield Landing



c. Shipboard Landing

Figure 42. Influence of SCAS configuration and wind environment on flying qualities.

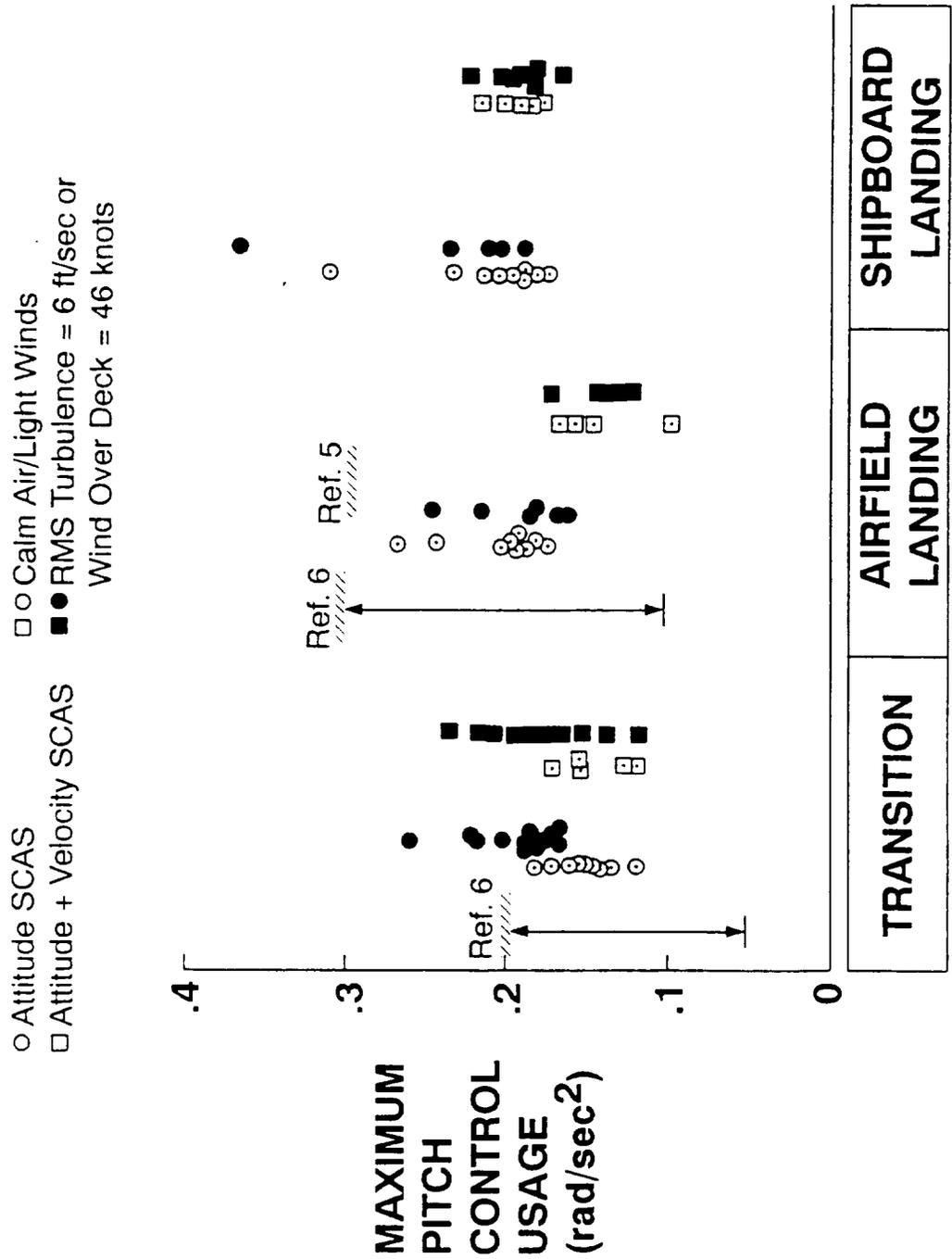


Figure 43. Influence of SCAS configuration and wind environment on pitch control use.

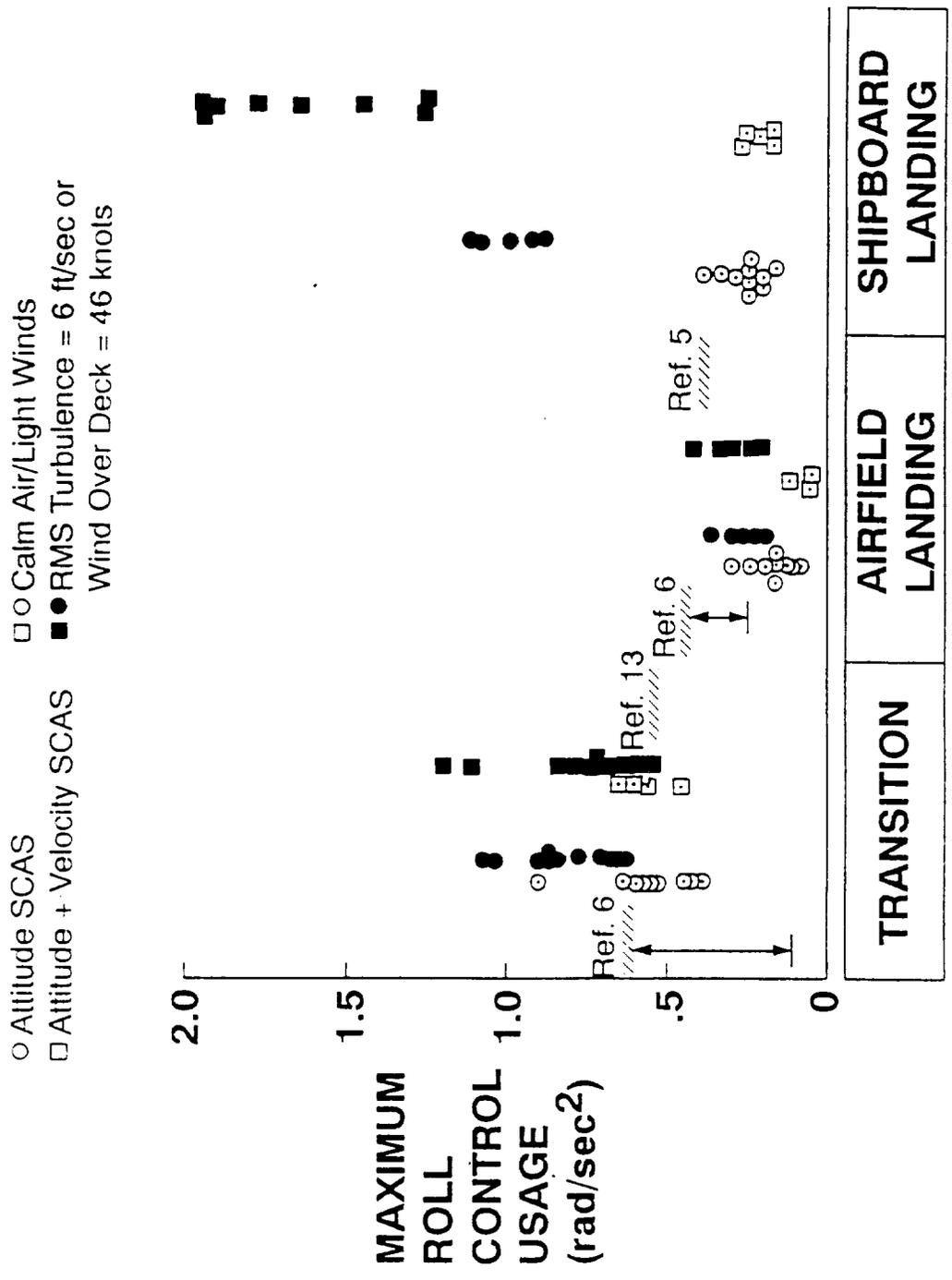


Figure 44. Influence of SCAS configuration and wind environment on roll control use.

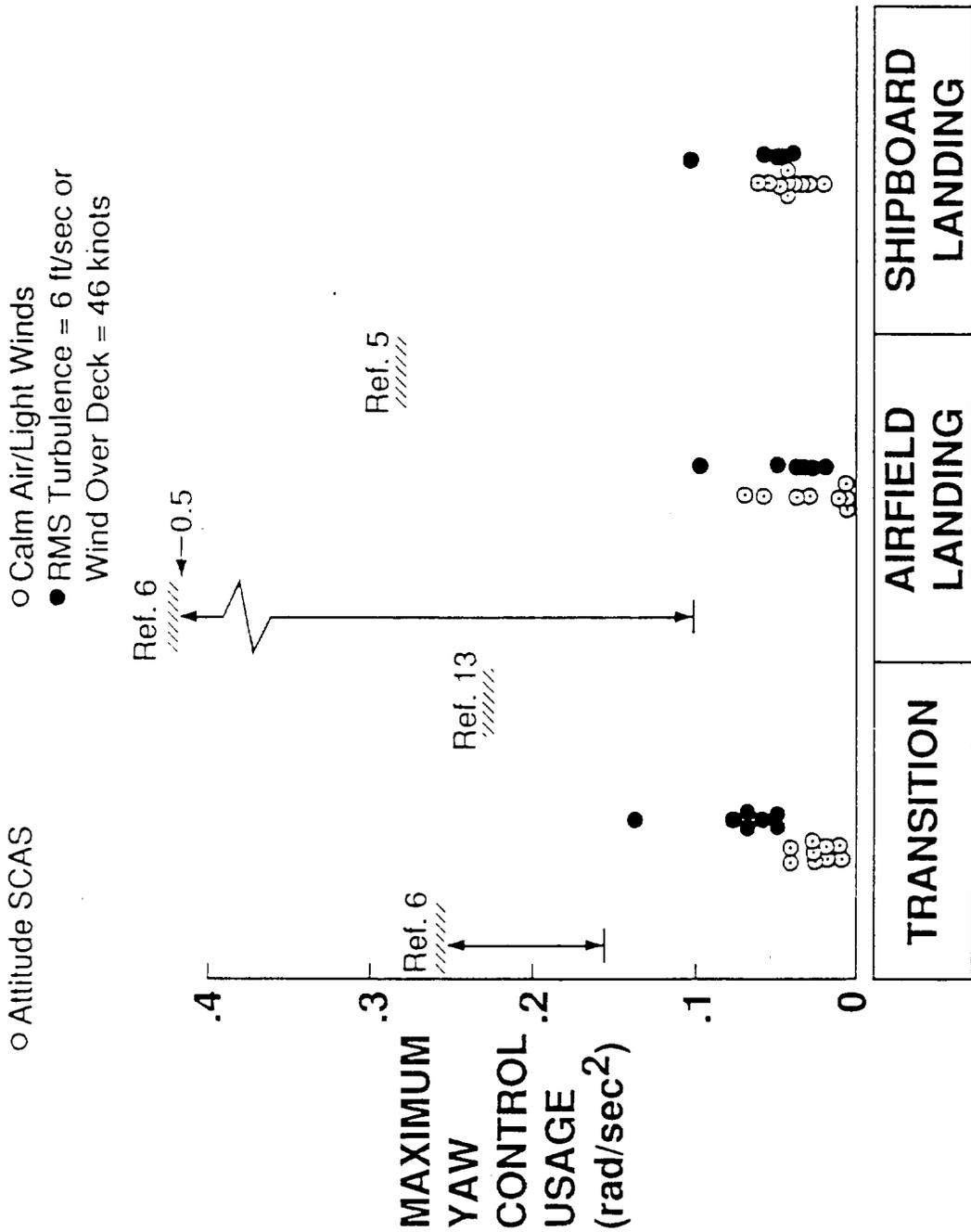


Figure 45. Influence of wind environment on yaw control use.

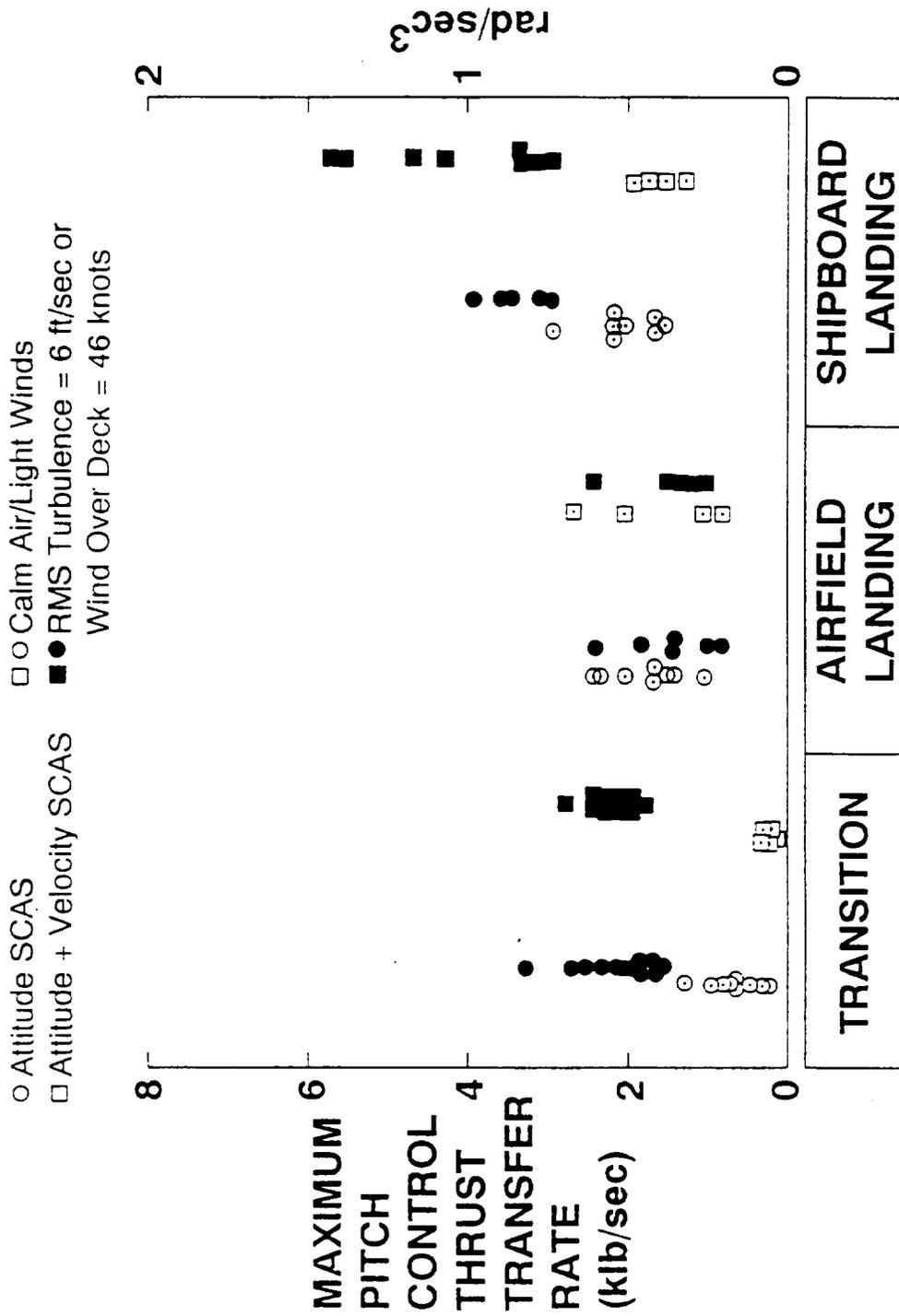


Figure 46. Influence of SCAS configuration and wind environment on thrust transfer for pitch control

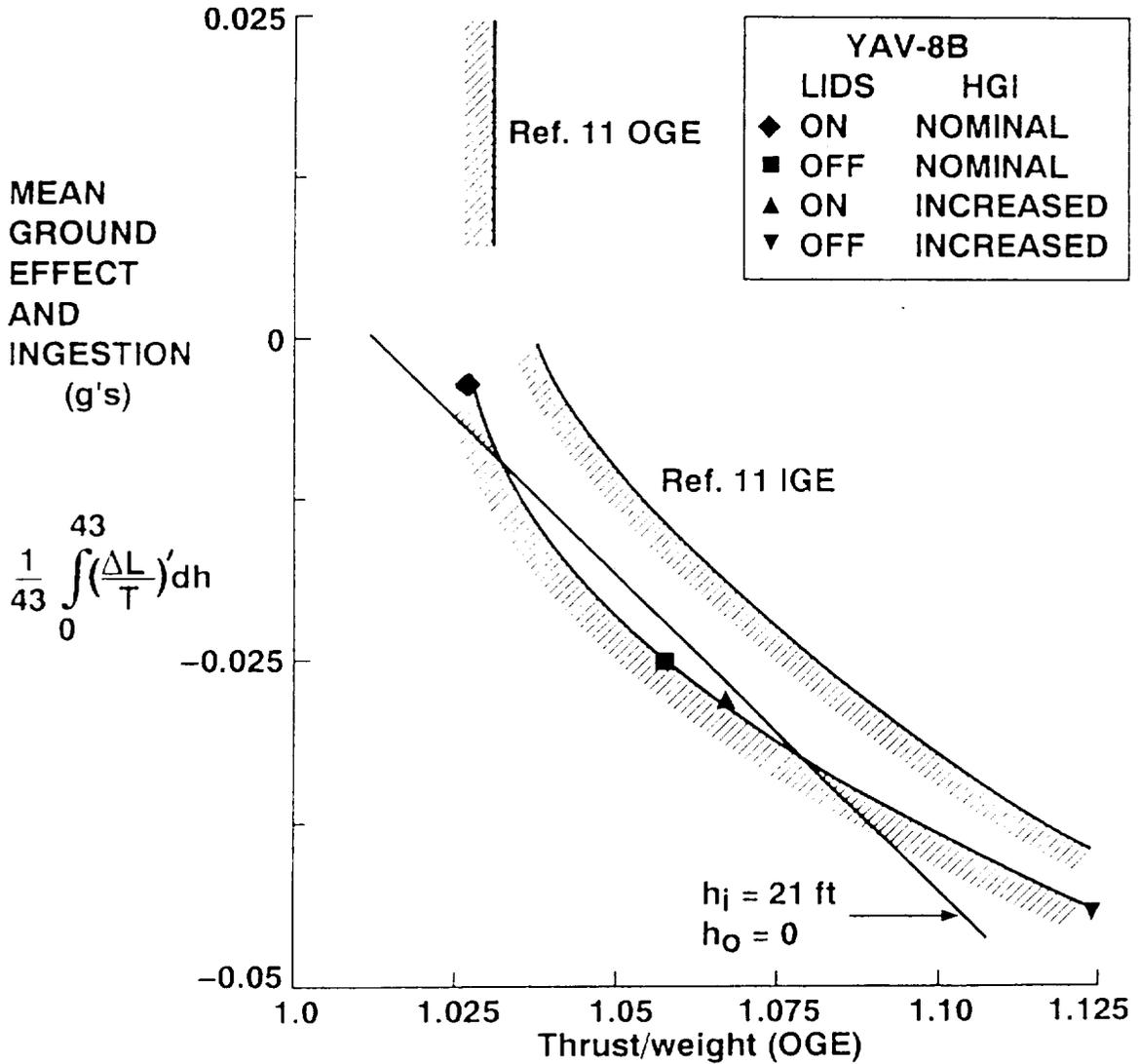


Figure 47. Influence of ground effect and hot gas ingestion on thrust margin for vertical landing.

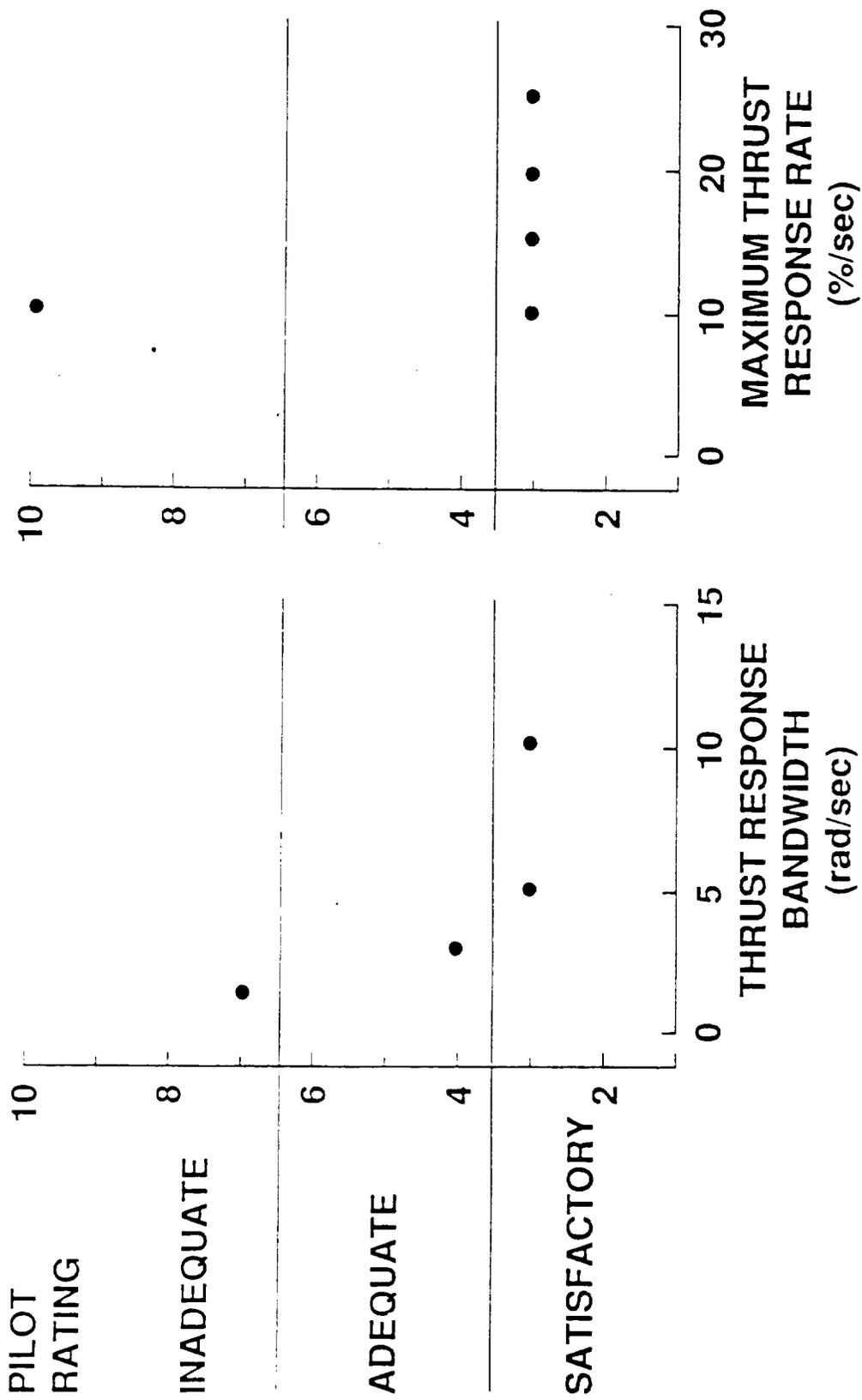


Figure 48. Effect of thrust response bandwidth and response rate on control of vertical landing.

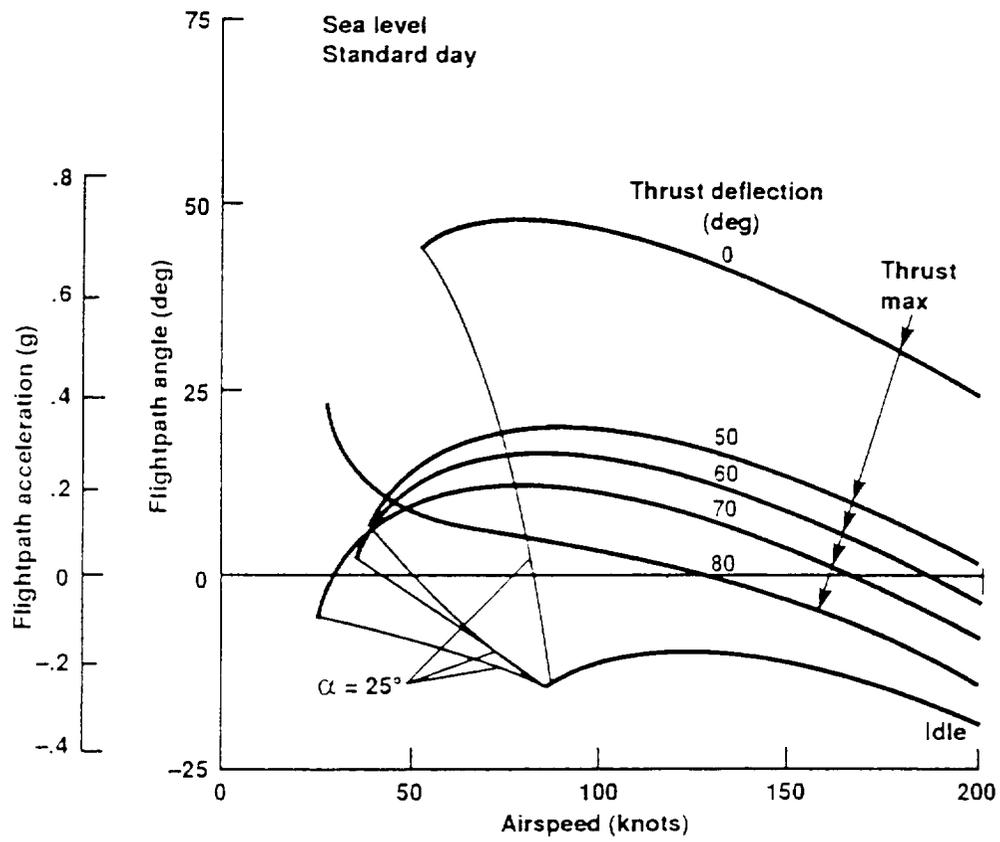


Figure 49. Transition flight envelope.

XV-5A Flight Tests

Figure 50 is a photo of the XV-5B, a slightly modified XV-5A. Figures 51 and 52 are drawings of US Army/GE/Ryan XV-5A. Features are 2 J85s, 2 62.5 in dia lift fans, 1 36 in dia pitch fan, 12500 lb max gross weight, first flight 1964.

Conventional helicopter controls: collective stick for height by wing fan exit louvers that spoiled or unspoiled fan thrust, longitudinal stick for pitch by pitch fan thrust reverser doors, lateral stick for roll by exit louvers for differential fan thrust, pedals for yaw by exit louvers to differentially vector fan thrust fore and aft. A throttle-mounted beeper controlled airspeed in fan-mode by collectively deflecting fan exit louvers.

Lessons learned from flight tests of the XV-5A:

- * Overall the aircraft performed well, and met the goal of validating the gas-driven fan-in-wing V/STOL concept.
- * Conversion mixer box had 70 relays that required "confidence check" during pilot's pre-flight--too complicated.
- * Lacked integrated powered-lift flight controls, hence too many controls, high workload, impossible for IMC.
- * Lateral and directional control decreased as collective increased. Less control just when needed for VTO and climbing through ground effect disturbances.
- * Landing-gear geometry required aircraft to be raised to level attitude for VTO--prohibited smooth VTOs.
- * Momentum drag of pitch fan caused weather-cock and directional instabilities during very low speed flight. Using a pitch fan in the fuselage nose was "far from optimal".
- * Conversion was "bang bang" type; "most exacting and potentially hazardous operational aspect of the XV-5A". Unacceptable--need gradual and reversible type conversion system.
- * Figure 53 shows the conversion airspeed corridor was narrow. Severely restricted operational flexibility and placed an unreasonable demand on pilot's adherence to procedures.
- * Conversion was accompanied by an abrupt pitch change of 10 to 15 deg. Required excessive coordination--unsafe for IMC.
- * J-85 diverter valve gas seal leaked, causing the covered lift-fan cavities to heat up. Fan cavity temperature indicators had to be monitored by the pilot.
- * Gas ducts to the pitch fan were routed under the cockpit floor. Conversion to fan-mode turned on the "heater". Cockpit temperatures could get uncomfortably high.
- * Outstanding was robustness of the gas-driven lift fans. Absence of drive shafts, shaft bearings, gear boxes, and pressure lube systems resulted in low maintenance and high confidence. Only indicators associated with the three fans were rpm and fan cavity temperature!

XV-5B Flight Tests

XV-5B was XV-5A modified with mechanical tie between stabilizer and diverter valve actuators, wider landing gear tread, improved fuel management system, and improved cockpit arrangement. First flight was 1968. Investigated steep terminal area approaches and aircraft noise footprints.

Lessons learned from flight tests of NASA Ames XV-5B:

* Figure 54 shows "deck parallel" descent envelope. Typical approaches were 10 deg flight path, 70 knots, 20 deg of thrust vectoring (point B, fig 5). Major source of handling problems was management of powered-lift. Needed was integrated system that would schedule engine power and fan lift controls in response to a single powered-lift controller.

* Two glide slope tracking procedures were used. Preferred was collective for direct-lift-control tracking. When engine power was used, lags in J-85 and lift fans caused the pilot to chase glide slope with throttle movements.

* Changing thrust vector angle was effective for controlling velocity during decelerating approaches. It did induce flight path disturbances, but the pilot could cope with them if vector changes were beeped in 10 deg increments.

* Figure 55 shows two procedures, deck level and deck parallel. For preferred deck parallel, the longitudinal axis was pointed along the glide slope by holding angle of attack near zero, thus operating lift fans at an angle of attack of zero. Deck level had potential of reducing fuel used (by replacing some fan lift with wing lift). Two adversities of deck level were (1) reduced fan stall margin which limited descent rate needed for fly-down slope corrections, and (2) random aerodynamic effects that hindered glide slope tracking. Unlike for deck parallel, deck level was operationally restricted from steeper than 10 deg glide slope angles.

X-14A Flight Tests

The X-14A was fitted with tip-turbine-driven lift fans in the wing tips for roll control. Flight tests are not summarized herein except to say the roll control system was unacceptable due to large fan speed first-order time constants and other factors. This finding does not negate the possibility that using light-weight fans having variable pitch blades might yield a satisfactory system.

Application of Lessons Learned to Supersonic STOVL Fighter

Lessons learned are organized into case histories, into design categories, and in Appendix II as applicable to a hypothetical supersonic STOVL fighter/attack aircraft, assumed to be single engine, single pilot, gas-driven fan-in-wing. A condensed Appendix II follows.

Merits of the gas-driven lift fan:

- * Robust, easy to maintain, easy to operate
- * Drive shafts, gear boxes, pressure lube-- vulnerable to enemy fire-- are not required
- * Pilot monitoring of health is minimum, fits single pilot
- * Resistance to FOD, fits operations from remote sites

Lift-fan limitations:

- * Eliminate nose pitch fan, use RCS.
- * Do not consider X-14 type roll control fans
- * Do consider using lift fan thrust spoilage system
- * Account for fan stall in specifying flight profiles

Fan-in-wing aircraft handling qualities

- * Provide integrated powered-lift management system
- * Provide Level I handling qualities

Conversion system design

- * Do not use "bang bang" conversion system
- * Use continuous, fully reversible conversion system
- * Conversion should be decoupled so pilot does not have to compensate for lift, attitude, or speed changes
- * Conversion controller should be single lever or beeper that is safety-interlocked
- * Provide wide conversion airspeed corridor

Terminal area approach operations

- * Integrated powered-lift system that provides decoupled flight path control for glide slope tracking
- * Single controller for direct flight path modulation
- * Lift fans with increased angle-of-attack capability to enhance IMC operations and improve safety

Human factors

- * Human factors are important. Though repetitious with previous sections, examples are confidence in lift fans, concern for approach to the fan stall boundary, high pilot workload tasks, and conversion controller design
- * Issue that concerned the author the most was cockpit arrangement.
- * Supersonic STOVL designers should take heed of "lessons learned"

Concluding Remarks

This is the pilot's perspective, written from an engineering test pilot's point of view. The author has 10,000 hours in 100 types of fixed-wing and rotary-wing, including 330 hours in 5 experimental V/STOL research aircraft.

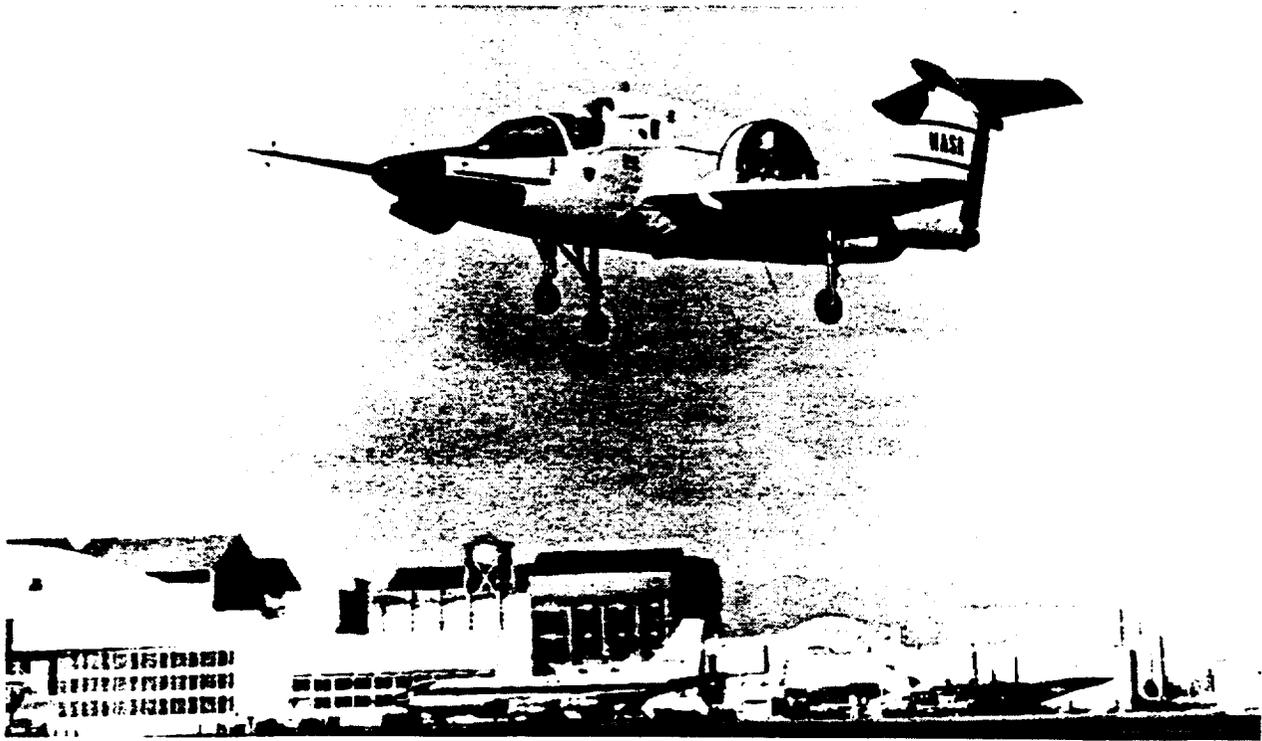


Figure 50. XV-5B airplane in hover flight.

1. PITOT MAST
2. FIBERGLASS NOSE CONE
3. G. E. X376 PITCH FAN
4. NOSE FAN THRUST CONTROL DOOR
5. NOSE FAN INLET CLOSURE DOORS
6. WINDSHIELD
7. NOSE FAN SUPPLY DUCT
8. RUDDER PEDALS
9. INSTRUMENT PANEL
10. CONVENTIONAL CONTROL STICK
11. OBSERVER'S EJECTION SEAT
12. NOSE LANDING GEAR
13. THROTTLE QUADRANT
14. PILOT'S EJECTION SEAT
15. COLLECTIVE LIFT STICK
16. HYDRAULIC EQUIPMENT COMPARTMENT
17. SINGLE SPLIT ENGINE INLET DUCT
18. ELECTRICAL EQUIPMENT COMPARTMENT
19. HYDRAULIC PUMP
20. FWD MAIN FUEL TANK
21. GENERATOR
22. RIGHT WING
23. G. E. J85-5 GAS GENERATOR
24. AILERON, R.H.

25. CROSS-OVER DUCT
26. WING FAN LOUVER ACTUATORS
27. DIVERTER VALVE
28. WING FAN INLET CLOSURE DOORS
29. G. E. X353-5B LIFT FAN
30. ENGINE TAIL PIPE
31. TWO POSITION MAIN LANDING GEAR
32. LEFT WING
33. AILERON, L.H.
34. WING FLAP, L.H.
35. THRUST SPOILER, L.H.
36. EXTERNAL LONGERON
37. VERTICAL FIN
38. FULL MOVEABLE HORIZONTAL STABILIZER
39. ANTI-SPIN AND DRAG COMPARTMENT
40. RUDDER
41. ELEVATORS

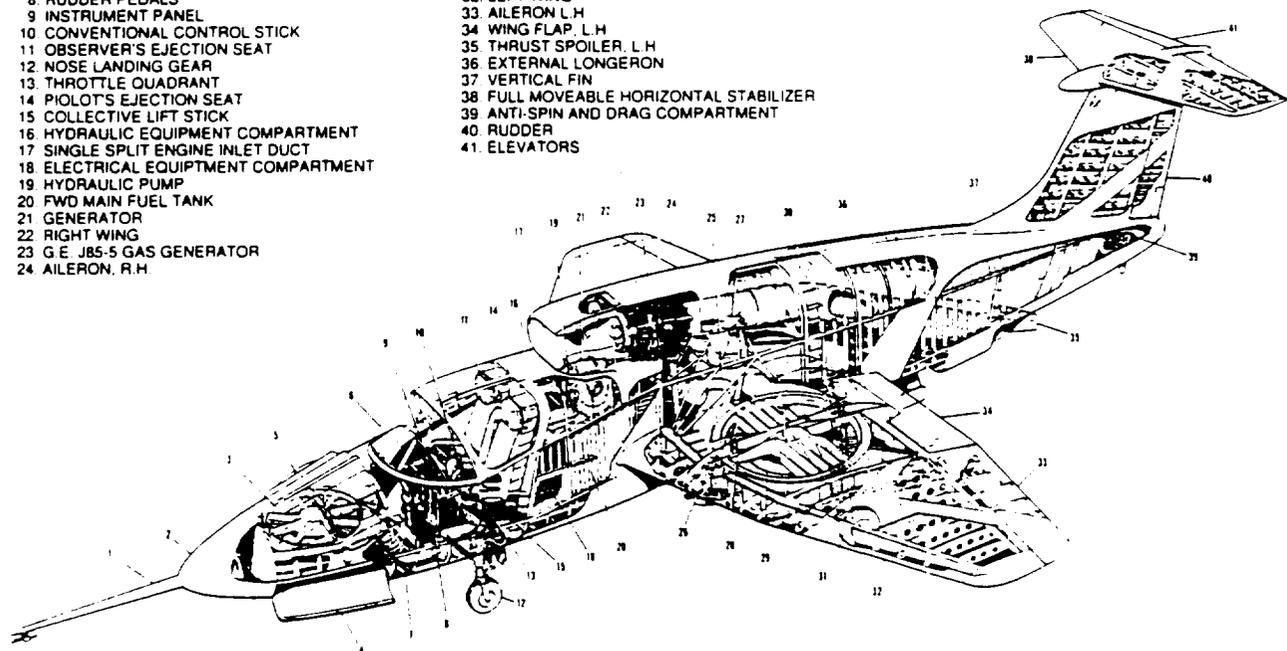


Figure 51. XV-5A aircraft cutaway drawing.

- 1 NOSE FAN
- 2 GAS GENERATOR
- 3 DIVERTER VALVE
- 4 ENGINE TAIL PIPE
- 5 WING FAN
- 6 CROSSOVER DUCTS
- 7 NOSE FAN SUPPLY DUCT
- 8 LEFT WING FAN SCROLL
- 9 RIGHT WING FAN SCROLL
- 10 NOSE FAN SCROLL

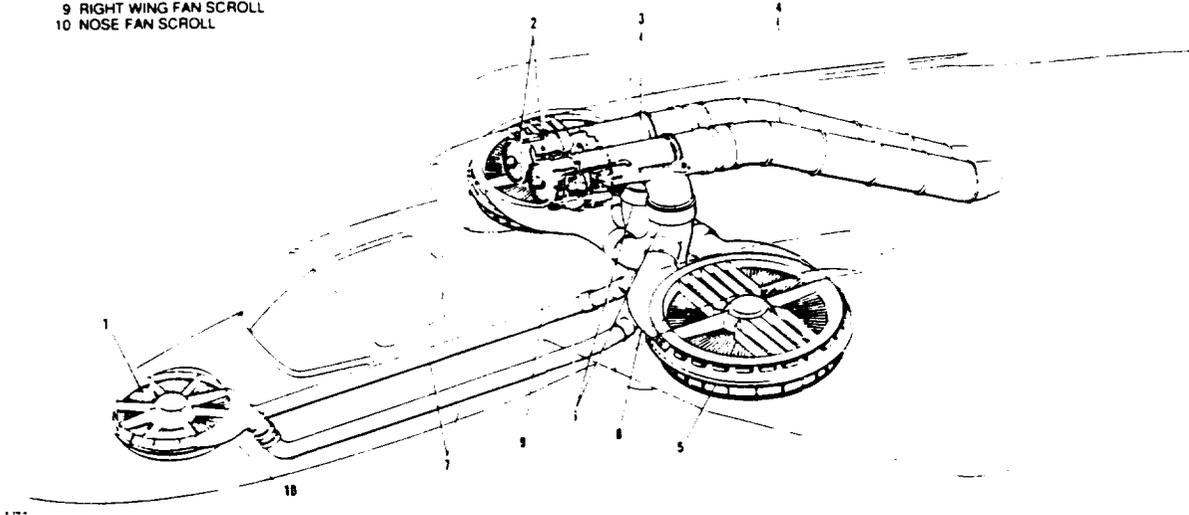


Figure 52. XV-5A propulsion components.

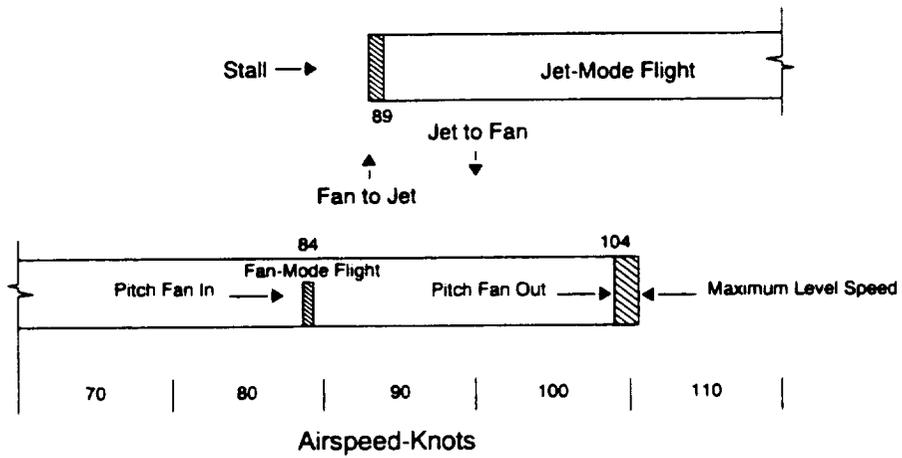


Figure 53. XV-5A safe conversion airspeed corridor.

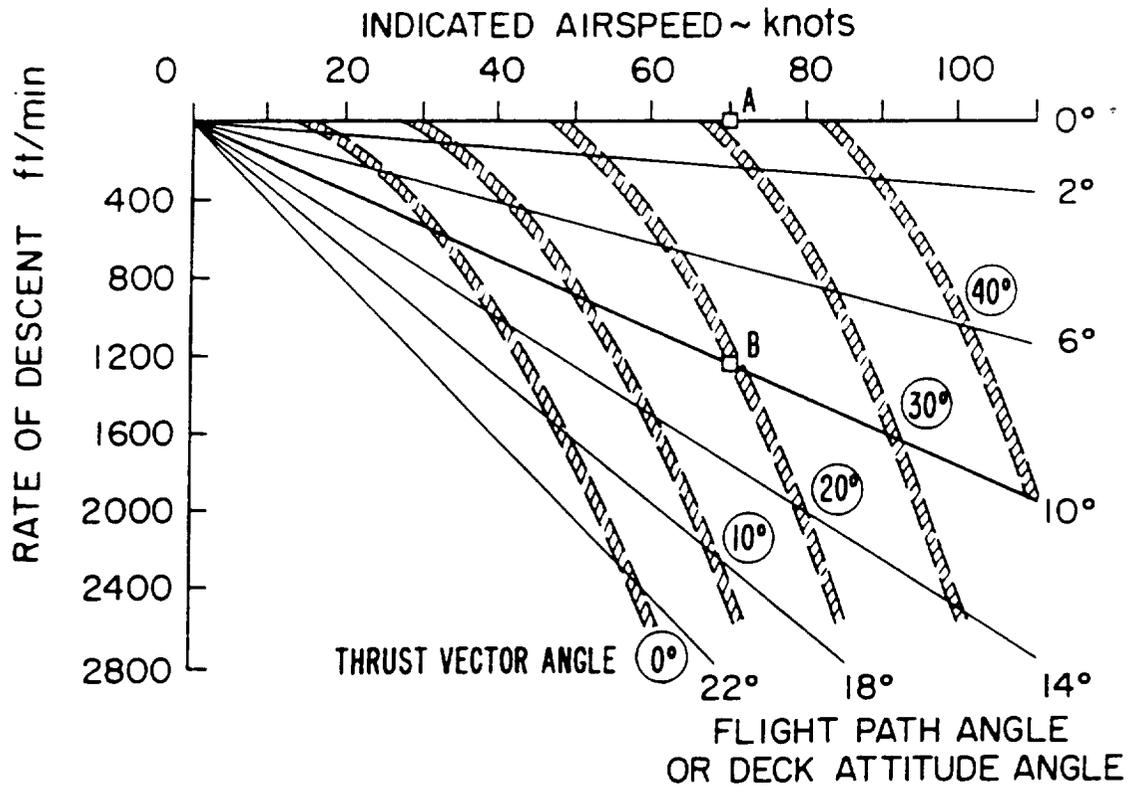


Figure 54. XV-5B deck-parallel terminal approach envelope.

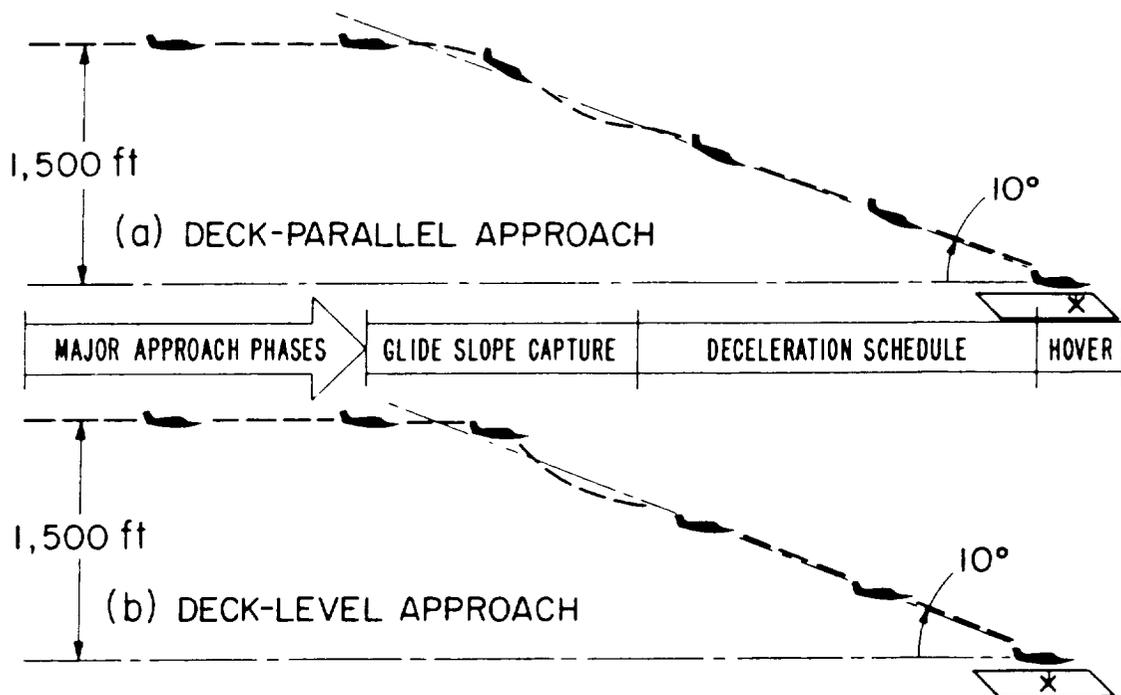


Figure 55. XV-5B terminal area procedures.

References

1. Deckert, Wallace H., "The Lift-Fan Powered-Lift Aircraft Concept: Lessons Learned." NASA CR-177616, September 1993.
2. Hickey, David H. and Kirk Jerry V., "Survey of Lift Fan Aerodynamic Technology." NASA CR-177619, August 1993.
3. Cook, Woodrow L., "Summary of Lift and Lift/Cruise Fan Powered Lift Concept Technology." NASA CR-177619, August 1993.
4. Franklin, James A., "Lift Fan Aircraft Technology Review: Simulation Programs." Presented at the NASA Ames Research Center Workshop "The Lift-Fan Aircraft: Lessons Learned," 1992.
5. Gerdes, Ronald M., "The Lift-Fan Aircraft: Lessons Learned--The Pilot's Perspective." NASA CR-177620, August 1993.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE March 1995	3. REPORT TYPE AND DATES COVERED Contractor Report	
4. TITLE AND SUBTITLE The Lift-Fan Aircraft: Lessons Learned			5. FUNDING NUMBERS NAS2-5364D	
6. AUTHOR(S) Wallace H. Deckert				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Ames Research Center Moffett Field, CA 94035-1000			8. PERFORMING ORGANIZATION REPORT NUMBER A-95041	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001			10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA CR-196694	
11. SUPPLEMENTARY NOTES Point of Contact: Clark White, Ames Research Center, MS 237-2, Moffett Field, CA 94035-1000 (415) 604-5653				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified-Unlimited Subject Category - 05			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This report summarizes the highlights and results of a workshop held at NASA Ames Research Center in October 1992. The objective of the workshop was a thorough review of the lessons learned from past research on lift fans, and lift-fan aircraft, models, designs, and components. The scope included conceptual design studies, wind tunnel investigations, propulsion system components, piloted simulation, flight of aircraft such as the XV-5A and XV-5B and a recent lift fan aircraft development project.				
14. SUBJECT TERMS Lift-fan aircraft			15. NUMBER OF PAGES 63	
			16. PRICE CODE A04	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT	

